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THESIS

NAVY OFFICER MANPOWER OPTIMIZATION REVISITED

by

Michael G. Wheeler

March 2010

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13. ABSTRACT (maximum 200 words)

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NAVY OFFICER MANPOWER OPTIMIZATION REVISITED

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LIST OF ACRONYMS AND ABBREVIATIONS

BAH	Basic Allowance for Housing
BAS	Basic Allowance for Subsistence
CNO	Chief of Naval Operations
CNP/N1	Chief of Naval Personnel
DoD	Department of Defense
DoN	Department of the Navy
DV/p	Decision Variables and Parameters
FICA	Federal Insurance Contributions Act
FRE	Fleet Readiness Enterprise
FY	Fiscal Year
HYT	High Year Tenure
MPN	Military Personnel, Navy
MPT&E	Manpower, Personnel, Training, and Education
NCCA	Naval Center for Cost Analysis
NOC	Manual of Navy Officer Manpower and Personnel Classifications
NROTC	Naval Reserve Officers Training Corps
O1 … O6	Officer ranks: ensign, lieutenant junior grade, lieutenant, lieutenant commander, commander, and captain; respectively
OCO	Overseas Contingency Operations
OCS	Officer Candidate School
OHA	Overseas Housing Allowance
POM	Program Objectives Memorandum
PR	Program Review

RCMOP	Requirements-Driven Cost-Based Manpower Optimization
RCMOP-2	Revised Requirements-Driven Cost-Based Manpower Optimization
RPA	Retired Pay Accrual
SECNAV	Secretary of the Navy
TFMMS	Total Force Manpower Management System
URL	Unrestricted Line (a general type of officer community)
USNA	United States Naval Academy
YCS	Years of Commissioned Service
YOS	Years of Service

EXECUTIVE SUMMARY

This research analyzes an extension of the Requirements-Driven, Cost-Based, Manpower Optimization (RCMOP) model introduced by LT David Clark at the U.S. Naval Postgraduate School in 2009. RCMOP is a linear optimization program that simultaneously guides monthly values for U.S. Navy officer manpower variables, including inventory, promotions, accessions, designator transfers, and forced and natural losses, over a two-year time horizon. RCMOP minimizes the adverseness of fit between a given personnel inventory and a set of billet requirements, subject to fiscal and other manpower constraints. Fit is measured in terms of a "gap index," which employs linear penalties for unfilled billets. In order to increase the fidelity of results, we revise RCMOP as RCMOP-2, which enhances its predecessor by employing non-linear penalties for billet vacancies, and by adding resolution to the input data, among others.

Increased data resolution and extension of the planning horizon from two to four years significantly impacts the solution quality. In particular, RCMOP's uses a generic designator "Other" to aggregate officers in non-warfighting designators. In RCMOP-2, this category has been divided into four individual communities (Intelligence, Supply Corps, Civil Engineering and Other Restricted Line), with the first three comprising 45% of the original. Technically, this represents an important, realistic model restriction, because RCMOP has the potential to allocate some personnel in the "Other" community to jobs for which they are not actually qualified. Despite this restriction, the additional two years of time horizon allow RCMOP-2 to reduce the overall gap to 4.04%, mainly due to the effective management of the flow of officers below the rank of lieutenant. In other words, given the extended horizon, RCMOP-2 has visibility of, and capability to narrow, the initial inventory shortfalls at lower ranks. Unfortunately, for higher ranks (lieutenant commander and above) RCMOP-2 can only manage the initial inventory, with limited opportunities for promotions. We find that, in many instances, suggested promotion figures deviate from the actual limits prescribed by law. This suggests assessing the effect of extending the planning time to 20 or 30 years, as well as explicitly enforcing promotion limits in the model.

Non-linear penalty functions, which we approximate as piece-wise linear functions, render better solutions than their linear counterparts in RCMOP. For example, in the absence of sufficient manpower, RCMOP may sacrifice a disproportionate amount of 1000-coded billets if the (linear) weight for unfilled requirements in that category is smaller than for other jobs. By introducing a varying (non-linear) weight, RCMOP-2 disperses unfilled jobs across multiple billet categories more evenly, which is consistent with current practice.

As a final exercise, we compare several natural loss rate scenarios. (Natural losses, as opposed to forced losses or high-year tenure losses, are calculated as a fraction of the existing inventory, typically indexed by designator and years of commissioned service.) The motivation for these excursions is apparent: natural losses are difficult to estimate accurately, and therefore are perceived as a key unknown affecting manpower plans. Employing historical loss rates, we posit loss projections on observed rates similar to those in 2006-2008. In our final range of scenarios, over four years, losses may deviate from our baseline scenario by a factor of 0.74 to 1.22, yielding relative differences in our gap index of less than 10%, with a slightly higher difference in the non-weighed number of unfilled jobs. This suggests that RCMOP-2 is not very sensitive to natural loss rate changes, and can accommodate those changes without significantly impacting the outcome.

RCMOP-2 also signals a need for an increase in OCS accessions by at least 25% (the increase limit imposed in RCMOP-2) with respect to current plans. These additional accessions allow the model to leverage ensigns in order to reduce penalties for jobs up to lieutenant ranks.

We also find that the available budget never becomes a binding constraint, and yearly costs remains at approximately 10% below budget. Finally, RCMOP-2 unveils some end-effect consequences, especially in unusual increases in forced losses in the last months of our four-year horizon. This suggests pursuing the abovementioned time horizon extension as a future step in improving RCMOP-2.

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) utilizes the Planning, Programming, Budgeting, and Execution System as both policy and program to manage its resources, simultaneously considering near-, intermediate-, and long-term objectives. The Department of the Navy (DoN) mirrors the DoD process. One key element of this process is the biannual submission of the Program Objectives Memorandum (POM) by the Chief of Naval Operations (CNO) to the Secretary of the Navy (SECNAV) on even years. The POM estimates resources required by DoN to meet national strategic objectives over the next six years. The nearest two years contain significantly more detail than the following four years of estimates.

The DoN budget contains three major cost categories: military personnel, operations and maintenance, and investments (e.g., basic pay for sailors, aircraft fuel, and ships, respectively). This budget is premised on peacetime operations. Any increase in operations, also increases the Navy's fiscal requirements, which are authorized by Congress in the form of supplemental appropriations for overseas contingency operations (OCO). The costs of these three major DoN budget areas have risen steadily over the past few fiscal years (FYs), while OCO appropriations have declined over the same period (Table 1).

	FY 2007	**FY 2008**	**FY 2009**	**FY 2010**
Military Personnel	38.0	39.6	41.5	44.3
Operations and Maintenance	37.3	40.4	41.3	43.0
Investments	51.9	59.5	63.9	69.1
Supplemental Appropriations	24.5	25.7	7.3	-
OCO Request	-	-	8.7	15.3
DoN Total Budget	**151.7**	**164.8**	**163.8**	**171.7**

Table 1. DoN Budget Trends, FY 2007–10 (Dollars in Billions). [Office of the Budget 2009]

Mounting external and internal fiscal pressures in recent years compelled Navy leadership to adopt a more business-like approach to naval affairs. Navy Enterprise is the organizational construct designed to improve efficient use of resources. While Navy Enterprise focuses on the highest levels of leadership in the Navy (including SECNAV and CNO), the bulk of the organization resides in a smaller subset: Fleet Readiness Enterprise (FRE), which includes individual warfare enterprises and providers. Individual warfare enterprises are: Naval Aviation Enterprise, Surface Warfare Enterprise, Undersea Enterprise, Naval Netwar/FORCEnet Enterprise, and Naval Expeditionary Combat Enterprise. Enterprises and providers work cooperatively to best employ current and planned Navy resources in execution of the National Maritime Strategy. FRE owns the “alignment and process for delivering ready forces for tasking.” Providers deliver future capability and readiness to individual warfare enterprises at optimal cost [Navy Enterprise 2008]. Figure 1 illustrates relationships necessary to balance current versus future readiness of the Navy. Specifically, manpower, personnel, training, and education (MPT&E) is one such provider within FRE, and the Chief of Naval Personnel (CNP) bears the responsibility of ensuring the Navy’s MPT&E needs are met across the spectrum of warfare enterprises.

Providers	**Individual Warfare Enterprises**				
	NAE	SWE	USE	NNFE	NECE
Manpower, Personnel, Training, and Education					
Naval Sea Systems Command					
Naval Air Systems Command					
Space and Naval Warfare Systems Command					
Naval Facilities Engineering Command					
Naval Supply Systems Command					
Office of Naval Research					
Commander, Navy Installations Command					
Bureau of Medicine and Surgery					

Figure 1. FRE within Navy Enterprise. [Navy Enterprise 2008]

> It [Navy Enterprise] is about collaborating, sharing, and enhancing our business practices. Not to turn the Navy into a business, but to understand the business of the Navy so that we remain the most effective and efficient Navy in the world. [Roughead, March 2008]

Additionally, CNP is responsible for meeting fiscal limitations specified in the congressionally approved budget. Herein lies the first challenge: Balancing the end strength personnel desired by each individual warfare enterprises while meeting fiscal requirements for any given budget year. When multiple fiscal years are considered, the second challenge becomes apparent: Managing Navy manpower to support both current needs and long-term force stability (in terms of both end strength and cost), and capability to support future requirements.

The costs for military personnel managed by CNP are a significant part of the DoN budget. Historically, manpower costs have remained nearly 25% of the total DoN budget in recent years. Planned expenditures for military personnel, Navy (MPN) exceeded $23 billion in each of the last three FYs, and proposed expenditures for FY 2010 exceed $24.5 billion (Table 2). *Note*: Table 1 includes manpower costs associated with U.S. Navy and U.S. Marine Corps military personnel. Table 2 includes *only* costs for active duty U. S. Navy personnel.

	FY 2007	**FY 2008**	**FY 2009**	**FY 2010**
Pay and Allowances of Officers	6,000	6,200	6,458	6,938
Pay and Allowances of Enlisted	15,370	15,322	15,747	15,506
Pay and Allowances of Midshipmen	63	61	63	70
Subsistence of Enlisted Personnel	908	902	950	1,039
Permanent Change of Station Travel	719	723	663	772
Other Military Personnel Costs	125	111	156	178
Total: MPN	**$23,185**	**$23,318**	**$24,038**	**$24,504**

Table 2. Planned MPN Spending for Active Duty Navy Personnel (Dollars in Millions). [Office of the Budget 2007–2009]

Annually, the CNO provides guidance on his vision for the Navy. Balancing effectiveness, efficiency, and risk has been an underlying theme over recent years [Roughead 2007–2009]. This research explores the use of mathematical optimization to plan and apportion Navy manpower. These efforts are consistent with ongoing CNO guidance and the MPT&E effort across individual warfare enterprises.

B. OVERVIEW OF NAVAL OFFICER MANPOWER PLANNING

The distinction between officer and enlisted personnel is the broadest classification of personnel within the U.S. military, including the U.S. Navy. Both categories have distinct characteristics such as inventory levels, loss rates, career fields, and associated career paths. Historically, officer ranks possess smaller inventories that exhibit more stability with regard to other characteristics than enlisted personnel. Officer ranks are the focus for this research. The critical elements that drive the manpower planning process are work requirements, fiscal limitations, budget programming, end strength, billet authorizations, and succession planning, as described in the remainder of this section.

1. Work Requirements

Work requirements for Navy officers are, in essence, the specific jobs and tasks necessary to achieve the Navy's mission. This mission is shaped through guidance from several sources: the National Security Strategy, National Defense Strategy, and National Military Strategy [Brown 2009]. These strategic documents provide a framework in which the National Maritime Strategy must fit, and a context for leaders within FRE to make decisions. Individual warfare enterprises interpret strategic goals and quantify needs to accomplish these objectives. Needs are quantified in several dimensions, including force structure and manpower (e.g., types and number of ships, and personnel to operate them). The Naval Manpower Analysis Center is heavily involved in manpower requirements estimates across the various warfare enterprises. The process of developing work requirements considers neither fiscal constraints nor end strength limitations, and represents unbounded work requirements.

2. Fiscal Constraints and Budget Programming

The Navy budget is discretionary spending within the U.S. federal budget, and is approved annually by the Congress. This congressional appropriation is an upper bound on spending. Table 2 shows authorized expenditures for pay and allowances of active Navy officers in FYs 2007-10.

Over time, projected manpower needs become current manpower needs. Budget programming expresses the expected manning levels in dollars rather than in terms of people or man-hours. The budget program office compares the cost of manning plans to the estimates of available fiscal resources. This comparison provides insight into the affordability of a proposed manpower plan. While cost is a significant factor, the "best" manpower plan is not always the least costly. A viable manpower strategy is published biannually on even years as part of the POM, and adjusted on odd years during the Program Review (PR).

3. End Strength

Yardley et al. [2005] give a comprehensive outline of various laws and policies governing military personnel. In particular, they highlight applicable mandates by the U.S. Congress. U.S. Code, Title 10 Section 115 allows Congress to set personnel strength levels (known as "end strength") for each FY. Sections 521 and 523 of that Code are also noteworthy: Section 521 requires the Secretary of Defense to set strength levels for active duty officers above the rank of chief warrant officer at the end of each FY; and, Section 523 controls distribution of officers in ranks of lieutenant commander, commander, and captain (O4, O5, and O6 respectively), effectively placing an upper limit on the number of officers in each of these grades.

4. Billet Authorization

Billet authorization within the Navy is the process wherein decisions are made on which work requirements will be funded, given the current fiscal and end-strength limitations. Historically, the Navy's manpower budget has been slightly less than the cost of its work requirements. This shortfall forces resource sponsors (e.g., Navy Enterprise providers) and individual warfare enterprises to seek efficiencies within their organizations, and also fosters competition for billet funding among these groups.

5. Succession Planning

The Navy is fundamentally a hierarchical organization that promotes from within its ranks. Usually, an O6 within the Navy has served in every subordinate officer rank over a career that spans decades. Consequently, there is a flow of personnel from junior to senior ranks. Manpower planners manage this natural movement of personnel through the ranks, seeking to maintain appropriate personnel levels, skills sets, and promotion opportunities that meet both current and projected needs. Personnel loss rates, new officer accessions, promotions, and training of new and existing officers are all significant factors in succession planning.

C. RECENT PRACTICES AND RELEVANT ACADEMIC LITERATURE

Clark [2009] (and references therein) provides a sound review of recent trends in manpower planning and budget programming within the Navy. He further provides a comprehensive summary of germane literature for this research, which is partially brought into this document for completion. We briefly outline Clark's thoughts on current practice and then summarize selected academic efforts not previously discussed.

1. Recent Applications

Clark acknowledges an aversion to optimization models by both Navy planners and decision-makers. Dominant tools used by manpower planners include: (1) Markov-chain transition rates embedded with spreadsheet models, and (2) probabilistic based simulation models. Ease of use, modification and interpretation of these models may make them preferred over optimization models.

Budget planning practices have also evolved. A simplified explanation of a recent methodology is as follows: Estimate the cost per lieutenant from the current budget, multiply this cost by the desired number of lieutenants in a future FY and adjust for expected inflation. This approach has been superseded with a method that leverages the structure of FRE. Individual warfare enterprises outline current and future force requirements utilizing a “bottom-up” approach. This technique essentially entails detailing costs associated with each requirement. Aggregating these smaller costs provides a more credible cost estimate for today’s force as well as that of the future Navy.

Current manpower and budget practices identify personnel shortfalls and excesses. In essence, they provide a binary response: accept or reject the given plan. These tools are descriptive; therefore, they lack any capability to manipulate the shortfalls and excesses in any given plan to produce a better one. Insight on how to leverage shortfalls and surpluses may: (1) further improve an accepted plan, (2) improve a rejected plan to a degree that it becomes accepted, or (3) identify a rejected plan as the closest to acceptable.

2. Associated Literature

Edwards [1983] provides a general overview of manpower models, focusing on their application and underlying assumptions. He discusses the concept of a “manpower gap” as the disparity between supply and demand for manpower. We will build on this concept later in this document. Edwards generalizes promotion systems as “push” or “pull” asserting that “push” systems are well suited for Markov chain models, while “pull” systems lend themselves to renewal models. He notes that few promotion schemes are purely “push” or “pull,” but a blend of the two. Supplementing this reading with Gass [1991] provides a concise view of modeling techniques available to military manpower planners in the late 1980s and during the 1990s.

Durso and Donahue [1995] report on the role of optimization in the demobilization and strength reductions of the U.S. Army during the early 1990s. Their model characterizes Army personnel as a generalized network, and subsequently uses network properties and linear programming to minimize a weighted deviation from operating strength. In conjunction with Holz and Wroth [1980], there is a nearly 20-year history of the Army's use of linear programming as a significant tool in manpower management.

Tivnan [1998] examines optimal allocation of enlisted Marines to jobs in a bipartite elastic network, seeking to improve the existing assignment model used by the U.S. Marine Corps. His work allows personnel assignments to a job requirement of equal rank and one rank above or below the individual's rank (e.g., a person with rank E5 could be assigned to an E4, E5, or E6 job). This "one-up, one-down" concept is employed within the Navy today. Tivnan's work and earlier research by Morben [1989] are the only prior works we have discovered that address "one-up, one-down" assignment of personnel to jobs. Tivnan states that the U.S. Marine Corps' assignment model "has been in use since the 1970s," tallying a second service with at least 20 years of reliance on optimization as a manpower planning tool. Citing separate sources from Clark, Tivnan also portrays the Navy as reluctant to apply optimization-based tools to manpower problems.

D. THESIS OBJECTIVES AND ORGANIZATION

Current U.S. Navy manpower planning methods highlight problems such as unacceptable manning levels at certain ranks or time periods where manning levels and budget outlays do not support each other. Leveraging an optimal solution of U.S. Navy officer manning with fiscal constraints should either: (1) Increase percentage of requirements met for a fixed cost, or (2) meet a fixed requirement for a reduced cost. Either outcome represents an increased return on investment, across the full spectrum of Navy enterprises.

This work analyzes an extension of the Requirements-Driven Cost-Based Manpower Optimization (RCMOP) model developed by Clark [2009]. The extension, referred to as RCMOP-2, includes an approximation of non-linear penalties for unfilled manning requirements and other refinements. Specifically, this research exercises RCMOP-2 under varying conditions, and examines:

- The potential improvement by adding more resolution to the model and data. This includes grouping personnel into nine categories and examining work requirements in ten categories. The original model used five and six groups, respectively. Time horizon is also doubled from two to four years.
- The impacts of different non-linear penalty functions (approximated as piece-wise linear functions) for unfilled manning requirements.
- The sensitivity of model to personnel loss rate parameters.

In addition, we describe the development of a semi-automated tool to fuse multiple model output files from any single run and synthesize this information into customized graphical reports that help expedite analysis across multiple model runs.

As with the predecessor model, there is not an immediate expectation of a ready-for-use model, but improvements in RCMOP-2 increase the potential use of optimization, in conjunction with other methodologies, in addressing Navy manpower issues.

The remainder of this document is organized as follows: Chapter II presents the revised RCMOP model, to include the assumptions and mathematical formulation. Chapter III addresses the flow of information into and out of our model. In Chapter IV, we carry out three comparisons: the original and revised RCMOP models; various scenarios with linear and non-linear penalty rates; and, several cases of varying personnel loss rates. Chapter V summarizes significant findings, and suggests directions for future research.

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II. THE REVISED REQUIREMENTS-DRIVEN COST-BASED MANPOWER OPTIMIZATION MODEL

This chapter describes the revised RCMOP optimization model (see Salmerón [2010]), henceforth referred to as RCMOP-2. We discuss its underlying architecture, modeling assumptions, and mathematical formulation. Like its predecessor, RCMOP-2 measures the "fit" of officer personnel (supply) against given manpower requirements (demand) and seeks to minimize the inadequacy of this "fit." Following Clark [2009], we refer to this measure of fitness as the "gap index," and define it formally later in this chapter. The model uses a monthly time step to adequately depict the relationships between input data and output variables in the context of an annual budget over a four-year time horizon.

A. PERSONNEL FLOW DESIGN

Over time, Navy officers move through ranks and between designators in distinct ways, which can be viewed as flow (of personnel) in a time-phased network [Ahuja et al., 1993, pp. 737–40]. This flow remains a cornerstone of the RCMOP-2 model. Other side constraints, however, preclude us from solving RCMOP-2 as a network. Given that computational times for the scenarios analyzed in this thesis remain manageable, we have not explored the potential application of decomposition algorithms that take advantage of the partial network structure in the formulation.

Many manpower practices within the Navy use personnel data collected at a single point in time, and subsequent time series analysis projects those data into the future. In a similar fashion, RCMOP-2 counts officers in certain groups on the first day of each month, categorizing them by rank, designator, and years of commissioned service (YCS). We then use data and variables to adjust inventory levels over a given month, which in turn becomes the next month's inventory. Consider the population inventory of a specific rank r and designator d with y YCS in a given month t. The following month's (t + 1's) inventory is derived from the previous month's inventory adjusted by the gains and losses during month t. Figure 2 illustrates this concept. Gains and losses can be characterized in several ways, and Table 3 details those used in RCMOP-2 divided into three general categories: losses, gains, and exchanges.

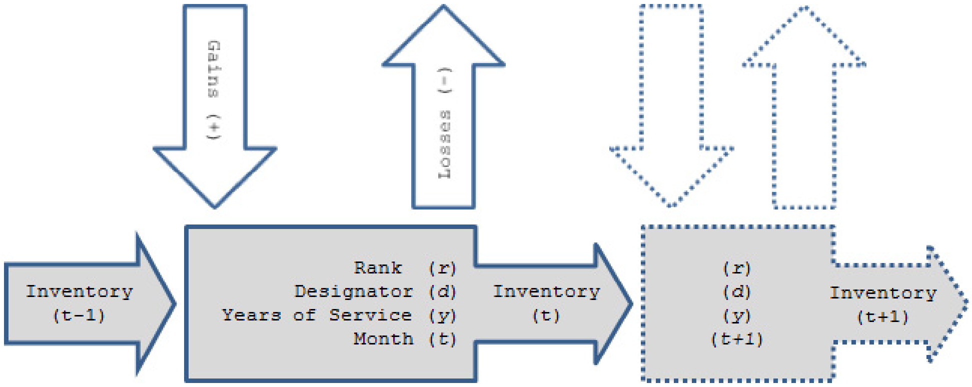

Figure 2. Inventory balance of flow concept.

	Description (RCMOP-2 notation)	***Role in RCMOP-2***
Losses	Natural losses (NLOSS)	Decision Variable
	Forced losses (FLOSS)	Decision Variable
	High-Year tenure (HYT)	Decision Variable
Gains	Accessions from the U.S. Naval Academy and Reserve Officers Training Corps (accessNAROTC)	Data
	Accession from other sources such as Officer Candidate School (ACCESSOCS)	Decision Variable
Exchanges	Promotion (PROM)	Decision Variable
	Transfer (TRF)	Decision Variable
	Promotion and Transfer (PROMTRF)	Decision Variable

Table 3. Categorical personnel movements in RCMOP-2.

Losses represent personnel leaving the Navy and reduce strength, while gains increase inventory through new officers beginning their naval service. The third category, exchanges, denotes personnel movements between ranks and/or designators. An exchange is simultaneously a loss *and* a gain that results in zero net change to Navy-wide end-strength numbers. Promotions are an example of exchanges: an individual is promoted out of one rank (loss) and into a new rank (gain), but the officer was in the Navy before *and* after the promotion, leaving Navy-wide inventory unchanged.

Of course, RCMOP-2 allows only certain types of gains and losses. For example, a promotion to certain ranks at certain YCS is explicitly disallowed to comply with Navy's regulation. Also, other constraints on the values for decision variables are applicable, as described later in this chapter.

B. MODELING ASSUMPTIONS

1. Rank, Designator, and Work Requirements

RCMOP-2 maintains its primary focus on naval officers from the rank of ensign (O1) through captain (O6) who account for nearly 97% of inventory [Office of the Budget, 2010]. Consistent with the previous assumptions made by Clark [2009], warrant officer and admiral ranks remain excluded from the RCMOP-2 model, due to their smaller sizes and less regular promotions when compared to other ranks.

There are dozens of unique billet and officer designators listed in the Manual of Navy Officer Manpower and Personnel Classifications (NOC) [Director, MPT&E Policy 2009]. Billet designators are used to describe work requirements, and officer designators characterize the professional expertise of individuals. The billet and officer designators aid in matching people with appropriate jobs. For modeling purposes, we aggregate both the jobs and personnel designators into related groups (Table 4) and assign which designators are "eligible" to perform analogous jobs (Figure 3).

Description	*Designator Abbreviation*	*Work Requirement*
Naval aviators	AVIAT	jAVIAT
Special warfare and operations officers	SPEC	jSPEC
Submarine warfare officers	SUB	jSUB
Surface warfare officers	SWO	jSWO
All other unrestricted line officers	URL-OTHER	jURL-OTHER
Intelligence officers	INTEL	jINTEL
All other restricted line officers	RL-OTHER	jRL-OTHER
Supply Corps officers	SUPPLY	jSUPPLY
Civil Engineering Corps officers	CEC	jCEC
General purpose billets (e.g., those coded 1000, 1020 and 1050)	N/A	j1000

Table 4. Summary and description of designators and work requirement categories.

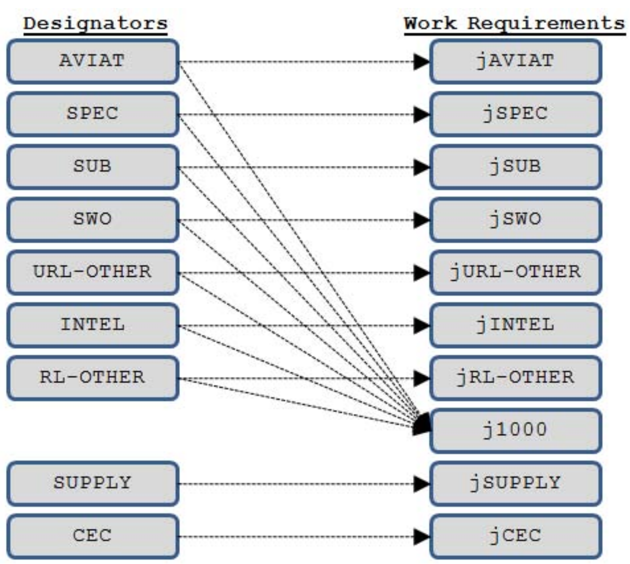

Figure 3. Mapping of possible personnel to job assignments. (Abbreviations listed in Table 4.)

This aggregation may neglect nuanced details of billet and officer designators listed in the NOC. For example, billets coded 1000 and 1050 are contained in our `j1000` category. In actuality, personnel in our `AVIAT`, `SPEC`, `SUB`, `SWO`, `URL-OTHER`, `INTEL`, and `RL-OTHER` categories may be assigned to 1000-coded billets, while 1050-coded billets are open only to personnel in our `AVIAT, SPEC, SUB,` and `SWO` groups and must be above the rank of O3.

The uncertainty regarding promotion timing and frequency also scopes our designator choices. Various laws, directives and policies permit certain officer communities to receive constructive credit for professional experience prior to entering the Navy, allowing accessions at the ranks other than O1 [Yardley 2005]. These groups largely comprise the Navy's Staff Corps officers many of which are modeled separately from other officer populations by manpower planners. Officer communities excluded from RCMOP-2 are Medical, Medical Service, Dental, Nurse, Chaplain, and Judge Advocate General Corps, each of which contains several designators.

2. Years of Service and Years of Commissioned Service

The Navy measures officer longevity in two distinct ways: years of service (YOS) and YCS. YOS measures the total time a member has spent in the Navy and YCS reflects the length of time served as an officer. YOS and YCS are the same for the majority of officers, but officers with any prior enlisted service have YOS greater than their YCS. However, for the purposes of this research, YOS and YCS are assumed to be identical and used interchangeably. The most important implication of this simplification is that RCMOP-2 will slightly underestimate the cost of those officers with YOS greater than their YCS. Based on this assumption, limited duty officers (who *must* have prior service) are excluded from the RCMOP-2 model due to the significant differential between their YCS and YOS. Efforts to characterize the relationships between YOS and YCS for prior service officers within our aggregated communities is ongoing, but was not completed during the time of this research.

A second simplification in this area involves the advancement of YCS. Every year, on the anniversary of their commissioning, officers earn credit for an additional YCS. The complexity of both our model and data makes tracking this anniversary for each individual untenable. Therefore, we assume that the officer population gains an additional year of service on May 1 of every year. This captures the majority of officers accessed from the U.S. Naval Academy (USNA) and the Naval Reserve Officers

Training Corps (NROTC) who are commissioned in May. However, certain officers, such as Officer Candidate School (OCS) graduates, might not be advanced accurately under this assumption. Intuitively, the early and late advancements should be roughly equal and offset each other, though this assertion has not been formally validated.

3. Lateral Transfers

Naval officers may request to transfer into another officer community, thereby changing their officer designator. Lateral transfers are based on personnel desires, community needs (i.e., both the gaining and losing community must permit a transfer), and personnel availability. It is possible for officers to transfer between most communities, but in practice, lateral transfers are normally from the unrestricted line (URL) communities (e.g., our `AVIAT`, `SPEC`, `SUB`, and `SWO` groups) into non-URL communities (e.g., our `INTEL`, `RL-OTHER`, `SUPPLY`, and `CEC` categories). For the purposes of RCMOP-2, we assume that URL officers serving in a warfare community may move laterally to non-URL communities (Figure 4).

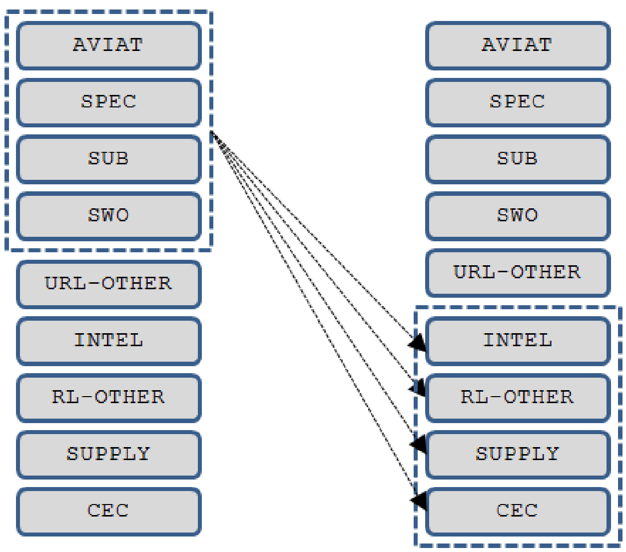

Figure 4. Mapping of possible lateral transfers.

4. Promotions, Promotion Zones, and High Year Tenure

Clark's discussion on Federal law, DoD directives, and DoN policies regarding promotions and high-year tenure (HYT) is still current. Promotions should occur within specified YCS windows, and the fraction of eligible officers who are promoted must fall within minimum and maximum percentages established by law. HYT forces officers who have failed to promote out of the Navy. These values vary by rank, as specified in Table 5.

Rank	YCS	YCS for Promotion (to rank)	Promotion Rate (to rank)	YCS for HYT
O6	21-29	21-23	40-60%	30
O5	15-27	15-17	60-80%	28
O4	9-19	9-11	70-90%	20
O3	4-11	4	100%	12
O2	2-3	2	100%	NA
O1	0-1	NA	NA	NA

Table 5. Summary table of YCS, promotion, and HYT values by rank. [Yardley et al., 2005]

RCMOP-2 does not constrain promotion rates to allow the model greater flexibility, which may signal needs for change in policy. The model may promote eligible officers (at a rate higher than allowed under current guidance) to mitigate the negative impact of job vacancies. Similarly, RCMOP-2 does not consider separate promotion zones within each promotion window, though, in actuality, below zone (or "early") promotions are limited to a maximum of 10% [Yardley et al., 2005].

5. Losses

In addition to HYT losses, RCMOP-2 also considers two other types of losses, namely natural losses and forced losses. Natural losses represent the recurring fraction of officers who do not continue their service for a variety of reasons: voluntary retirement (as opposed to forced retirement due to HYT), pursuing a civilian career following obligated service, disciplinary losses, and being found medically unfit for further duty.

Natural losses by designator and YCS are assumed to be a predetermined percentage of corresponding inventories. We further detail specific loss values used for our baseline scenario in Section III.A, and for other excursions in Section IV.C.

Forced losses denote a decision by Navy leadership to compel or influence personnel to leave the Navy, despite being qualified to remain on active duty. The significant end strength reduction in military personnel during the early 1990s provides several examples of forced losses. RCMOP-2 considers forced losses as a decision variable, which signals time periods when specific ranks and designators contain excess personnel.

6. Personnel Assignment and Requirements Matching

RCMOP-2 seeks to find the best "fit" of personnel inventory to work requirements over a four year time period. It is important to note that our model does not make individual personnel assignments, as considered by Tivnan [1998]. The process of detailing individuals to unique billets is a challenging and separate problem. RCMOP-2 recommends monthly allocation of aggregated quantities of personnel in a given rank and designator to a job type and rank, allowing a limited number of personnel to perform jobs requiring one rank above or below their actual rank.

C. WEIGHING LINEAR AND NON-LINEAR PENALTY FUNCTIONS

In both RCMOP and RCMOP-2, work requirements are assigned weights (w_j) indicating the relative importance of a specific job type. Higher weights indicate work requirements that, if left vacant, may have a more significant impact on the Navy's execution of its maritime strategy. In RCMOP, penalties are strictly linear, meaning that for a given weight, the penalty for not filling the first job is the same as the penalty for not filling the, say, hundredth or thousandth job. On the other hand, in RCMOP-2, we implement a non-linear, convex penalty function [Salmerón 2010].

RCMOP-2's non-linear penalty is built by partitioning each work requirement into several population segments (or tiers). As billets are not being filled, the population segment is noted and the penalty for that tier is assessed. As more billets remain unfilled, they move into subsequent tiers that have higher penalty rates. Tiers can be based, for example, on both the weight of the billet and percentage of that billet type that is unfilled. A comparison of percentage of the assessed penalty by fraction of the work requirement for linear and non-linear penalty functions is shown in Figure 5 (for a case with five tiers).

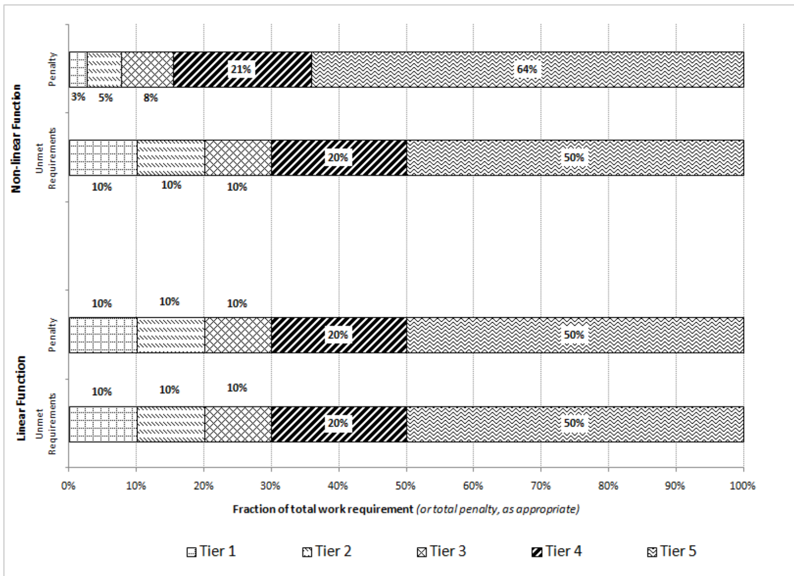

Figure 5. Percentage of penalty and population for linear and non-linear penalty functions.

Clark additionally notes that in RCMOP, all other things being equal, if weights between two jobs are not identical, the job with lesser weight always remains at a smaller penalty rate and is preferentially used to fill j1000 billets, transfers, etc. This preferential selection, results in lesser weight jobs bearing a disproportionate amount of the total penalty. Implementing a non-linear penalty helps distribute the unmet requirements more evenly between different job types. For example, consider requirements for Job A and Job B with weights of 75 and 100, respectively, with both billet types separated into five population tiers in Figure 6.

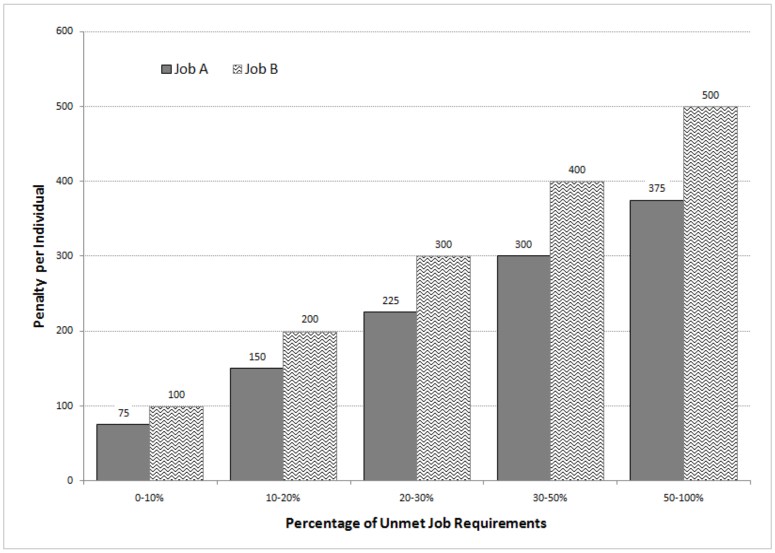

Figure 6. Non-linear penalties associated with different weights.

RCMOP-2 would initially prefer Job A's penalty (75) to Job B's penalty (100), until the first 10% of Job A billets had been used. At that point, Job B's penalty becomes preferred, since Job A's penalty is now increased to its next level of 150. This process repeats where a given job is preferred over the other until the given job reaches a tier that exceeds the current penalty of the other job.

D. MATHEMATICAL FORMULATION OF THE REVISED REQUIREMENTS-DRIVEN COST-BASED MANPOWER OPTIMIZATION MODEL

This section specifies the mathematical formulation of the RCMOP-2 model, and follows both Clark [2009] and Salmerón [2010].

1. Notation

Indices and Sets

$r \in R$	Officer Rank: *O1, O2, O3, O4, O5, O6*
$d \in D$	Designator: *URL-OTHER, SWO, SUB, AVIAT, SPEC, INTEL, RL-OTHER, SUPPLY, CEC*
$j \in J$	Job: *jURL-OTHER, jSWO, jSUB, jAVIAT, jSPEC, j1000, jINTEL, jRL-OTHER, jSUPPLY, jCEC*

$y \in Y$	Year Commissioned Service: *y0, y1,…, y29, y30*
$t \in T$	Planning Month: e.g., *Oct08, …, Sep12, Oct12*
$f \in F$	Fiscal Year: e.g., *FY2009, …, FY2013*
$k \in K$	Segment (a.k.a., bracket or tier) for non-linear penalty: e.g., *k1, …, k5*
RY	Subset of *(r,y)* pairs where it is possible that an officer with rank *r* has *y* YCS.
RY'	Extended subset of *(r,y)* pairs including the next-to-feasible YCS *y* for rank *r:* $RY' = RY \cup \begin{Bmatrix} (\mathrm{O1,y2}),(\mathrm{O2,y4}),(\mathrm{O3,y12}), \\ (\mathrm{O4,y20}),(\mathrm{O5,y28}),(\mathrm{O6,y30}) \end{Bmatrix}$
RY^H	Subset of *(r,y)* pairs where an officer of rank *r* and YCS *y* reaches HYT (see Table 5).
RY^P	Subset of *(r,y)* pairs where officers can be promoted to the next rank *r* in YCS *y* (see Table 5).
RR^F	Subset of *(r,r') pairs* where officers of rank *r* can fill work requirements in rank *r'*, i.e., $\begin{cases} (\mathrm{O1,O1}),(\mathrm{O1,O2}),(\mathrm{O2,O1}),(\mathrm{O2,O2}),(\mathrm{O2,O3}), \\ (\mathrm{O3,O2}),(\mathrm{O3,O3}),(\mathrm{O3,O4}),(\mathrm{O4,O3}),(\mathrm{O4,O4}), \\ (\mathrm{O4,O5}),(\mathrm{O5,O4}),(\mathrm{O5,O5}),(\mathrm{O5,O6}),(\mathrm{O6,O5}),(\mathrm{O6,} \end{cases}$
DJ	Subset of *(d,j)* pairs where an officer with designator *d* can fill a requirement in job field *j* (see Figure 3).
DD	Subset of *(d,d')* pairs where an officer with designator *d* can be transferred to designator *d'* (see Figure 4)
FT	Subset of *(f,t)* pairs where month *t* is in fiscal year *f.*
T'	Subset of months where YCS advancement occurs, i.e. *{May09, May10, May11, May12}*

Parameters [units]

$accessNAROTC_{r,d,y,t}$	The projected number of new officers accessed from USNA and NROTC sources into rank *r* and designator *d* with years of service *y* during month *t*. *[persons]*
$accessOCS_{r,d,y,t}$	The projected number of new officers accessed from OCS into rank *r* and designator *d* with years of service *y* during month *t*. *[persons]*
$minOCS$, $maxOCS$	The minimum and maximum fraction, respectively, of the projected OCS accessions, used to bound OCS accessions as determined by RCMOP. *[fraction]*
$req_{r,j,t}$	The work requirement for officers of rank *r* and field *j* at the start of month *t*. *[persons]*
$budget_f$	Total dollars available to fund the model-specific officer manpower for the fiscal year *f*. *[$]*
$cost_{r,y,t}$	The monthly cost of an officer in rank *r* and YCS *y* at the start of month *t*. *[$]*
$\alpha_{d,y}$	The monthly loss factor for officers with designator *d* and YCS *y*. *[fraction]*
$invent0_{r,d,y}$	The initial inventory of officers present on the first day of the first month with rank *r*, designator *d*, and YSC *y*. *[persons]*
w_j	The baseline weight (penalty) assigned to a shortfall within job field *j*. *[penalty units]* *Note*: Larger penalties are associated with higher priority work requirements.
l_k	Maximum fraction of unfulfilled jobs within bracket *k*. *[fraction]* *Note:* It is required that $\sum_k l_k = 1.0$
γ_k	Penalty coefficient for each unfulfilled job in bracket *k*, satisfying: $\gamma_1 < \gamma_2 < ... < \gamma_{\lvert K \rvert}$ *[scalar]*

$\beta_{r,d}$	The minimum fraction of officers with rank r and designator d that must fill work requirement of identical rank r (e.g., 95% of SWO O2 personnel must be assigned to an O2 billet). *[fraction]*
$\eta_{r,j}$	The maximum fraction of the total job requirement j and rank r that can be left unfilled. *[fraction]*

Derived Data [units]

$\overline{w}$ Maximum possible penalty; occurs when every work requirement remains vacant. *[penalty units $\times$ persons]*

Defined as:

$$\overline{w} = \sum_{r,j,t} \sum_{k} \gamma_k \, w_j \, l_k \, req_{rjt} \tag{1}$$

t_1 First month in set T, e.g., t_1 = "Oct08".

Variables [units]

$INVENT_{r,d,y,t}$	The number of officers present on the first day of month t with rank r, designator d, and YCS y. *[persons]*
$ACCESSOCS_{r,d,y,t}$	The number of new officers accessed from OCS into rank r and designator d with YCS y during month t. *[persons]*
$PROM_{r,d,y,t}$	The number of officers with designator d that are promoted into rank r, at the beginning of month t and with y YCS. *[persons]*
$TRF_{r,d,d',y,t}$	The number of officers with rank r that are transferred from designator d into designator d', at the beginning of month t and with y YCS. *[persons]*
$PROMTRF_{r,d,d',y,t}$	The number of officers that are promoted and transferred from designator d into rank r and designator d', at the beginning of month t and with y YCS. *[persons]*

$NLOSS_{r,d,y,t}$	The number of natural officer losses from rank *r*, designator *d*, and YCS *y* during month ***t*****.** *[persons]*
$FLOSS_{r,d,y,t}$	The number of forced officer losses from rank *r*, designator *d*, and YCS *y* during month ***t*****.** *[persons]*
$HYT_{r,d,y,t}$	The number of HYT officer losses from rank *r*, designator *d*, that would enter *y* YCS during month ***t*****.** *[persons]*
$FILL_{r,r',d,j,t}$	The number of officers in designator *d* with rank *r* that fill a work requirement in job field *j* and rank *r'* at the start of month *t*. *[persons]*
$KDEFICIT_{r,j,t,k}$	The shortage of officers needed to fill a given requirement in rank *r* and job field *j* at the beginning of month *t* within penalty bracket *k* *[persons]*
$SURPLUS_{r,j,t}$	The excess of officers filling a given requirement in rank *r* and job field *j* at the beginning of month t. *[persons]*

2. Formulation

<u>Objective Function:</u>

$$\min \frac{1}{\bar{w}} \sum_{r,j,t,k} \gamma_k \, w_j \, KDEFICIT_{r,j,t,k} \tag{2}$$

<u>Subject to:</u>

Inventory Initialization:

$$INVENT_{r,d,y,t} = invent0_{r,d,y} \quad \forall r,d,y,t \mid (r,y) \in RY', t = t_1 \tag{3}$$

Flow Balance Equations:

$$\begin{aligned}
INVENT_{r,d,y,t} = {} & INVENT_{r,d,y,t-1} + PROM_{r,d,y,t} - PROM_{r+1,d,y,t} \\
& - \sum_{d' \mid (d,d') \in DD} \left(PROMTRF_{r+1,d,d'y,t} + TRF_{r,d,d',y,t} \right) \\
& + \sum_{d' \mid (d',d) \in DD} \left(PROMTRF_{r+1,d',d,y,t} + TRF_{r,d',d,y,t} \right) \\
& - NLOSS_{r,d,y,t-1} - FLOSS_{r,d,y,t-1} - HYT_{r,d,y,t} \\
& + accessNAROTC_{r,d,y,t-1} + ACCESSOCS_{r,d,y,t-1} \\
& \qquad \forall r,d,y,t \mid (r,y) \in RY', t \notin T', t \neq t_1
\end{aligned} \tag{4}$$

$$
\begin{aligned}
INVENT_{r,d,y,t} = {} & INVENT_{r,d,y-1,t-1} + PROM_{r,d,y,t} - PROM_{r+1,d,y,t} \\
& - \sum_{d'|(d,d')\in DD} (PROMTRF_{r+1,d,d',y,t} + TRF_{r,d,d',y,t}) \\
& + \sum_{d'|(d',d)\in DD} (PROMTRF_{r+1,d'd,y,t} + TRF_{r,d',d,y,t}) \\
& - NLOSS_{r,d,y-1,t-1} - FLOSS_{r,d,y-1,t-1} - HYT_{r,d,y,t} \\
& + accessNAROTC_{r,d,y-1,t-1} + ACCESSOCS_{r,d,y-1,t-1} \\
& \qquad \forall r,d,y,t \mid (r,y) \in RY', t \in T'
\end{aligned} \tag{5}
$$

Fill and Requirements Constraints:

$$
\sum_{y|(r,y)\in RY'} INVENT_{r,d,y,t} = \sum_{r'|(r,r')\in RR^F} \sum_{j|(d,j)\in DJ} FILL_{r,r',d,j,t} \qquad \forall r,d,t \tag{6}
$$

$$
\begin{aligned}
req_{r,j,t} = {} & \sum_{r'|(r',r)\in RR^F} \sum_{j|(d,j)\in DJ} FILL_{r',r,d,j,t} \\
& + \sum_{k} KDEFICIT_{r,j,t,k} - SURPLUS_{r,j,t} \qquad \forall r,j,t
\end{aligned} \tag{7}
$$

$$
KDEFICIT_{r,j,t,k} \le l_k \; req_{rjt} \qquad \forall r,j,t,k \tag{8}
$$

$$
\sum_{j|(d,j)\in DJ} FILL_{r,r,d,j,t} \ge \beta_{r,d} \sum_{y|(r,y)\in RY} INVENT_{r,d,y,t} \qquad \forall r,d,t \tag{9}
$$

$$
\eta_{r,j} req_{r,j,t} \ge \sum_{k} KDEFICIT_{r,j,t,k} \qquad \forall r,j,t \tag{10}
$$

Loss Constraints:

$$
NLOSS_{r,d,y,t} = \alpha_{d,y} INVENT_{r,d,y,t} \qquad \forall r,d,y,t \mid (r,y) \in RY' \tag{11}
$$

Budget Constraints:

$$
BUDGET_f \ge \sum_{r,d,y,t|(r,y)\in RY',(f,t)\in FT} \mathrm{cost}_{r,y,t} INVENT_{r,d,y,t} \qquad \forall f \tag{12}
$$

Accessions Constraints:

$$\text{minOCS}\ accessOCS_{r,d,y,t} \leq ACCESSOCS_{r,d,y,t} \qquad \forall r,d,y,t \quad (13)$$

$$ACCESSOCS_{r,d,y,t} \leq \text{maxOCS}\ accessOCS_{r,d,y,t} \qquad \forall r,d,y,t \quad (14)$$

Exclusions:

$$INVENT_{r,d,y,t} = 0 \qquad \forall r,d,y,t \mid (r,y) \notin RY \quad (15)$$

$$HYT_{r,d,y,t} = 0 \qquad \forall r,d,y,t \mid (r,y) \notin RY^{H} \quad (16)$$

$$PROM_{r,d,y,t} = 0 \qquad \forall r,d,y,t \mid (r,y) \notin RY^{P} \quad (17)$$

$$PROMTRF_{r,d,y,t} = 0 \qquad \forall r,d,y,t \mid (r,y) \notin RY^{P} \quad (18)$$

Variable domains:
All variables are non-negative

3. Formulation Description

The objective function (2) of the RCMOP-2 model minimizes the total weighted gap index associated with the differences between personnel inventory and work requirements across fractional segments of the population over the model's time horizon. The objective function has been normalized to the interval [0, 1]. We calculate the maximum possible penalty (in which *every* job in the Navy remains unfilled), as derived data detailed in (1). If all jobs were left vacant our objective function would yield a value of 1. Conversely, if all requirements are met (i.e., all deficits are 0), then our objective function would have a value of 0.

Inventory is initialized in (3), and establishes the personnel supply available in October 2008. We then apply (4-5) to maintain the proper flow of personnel through ranks, designators, and YCS over time, conceptually illustrated in Figure 2, with specific personnel transactions detailed in Table 3. Note that (4) does not apply to either the first month of study (October 2008) or when a YCS increase occurs (May of any year). For the latter, a similar balance of flow (5) ensures a YCS increment for all personnel.

The `FILL` variables ensure that the entire inventory is utilized to meet specified job requirements in constraints (6-7) and are further discussed in Section IV.A. We report the excess and shortage of personnel inventory through the use of the *KDEFICIT* and *SURPLUS* variables. *KDEFICIT* describes magnitude of a shortfall within a specific bracket of a requirement and is bounded in (8) such that we cannot see a shortage in a bracket that exceeds the bracket's size. (9) ensures that a minimum fraction of a given rank's inventory (by designator) is allocated to perform jobs within the same rank, every month. Equation (10) constrains the fraction of the total deficit for each rank and job type, although we set this value to one in all of our scenarios, so that no requirement is enforced as a hard constraint.

Equation (11) calculates the monthly natural loss during the planning period. Validation of the fiduciary integrity of our manpower expenditures occurs in Equation (12). RCMOP-2 is afforded some limited deviations from planned OCS accessions, as outlined in (13-14). Equations (15-18) are logical constraints and preclude unauthorized pairings of certain variables.

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III. INFORMATION MANAGEMENT ARCHITECTURE

This chapter describes inputs into RCMOP-2 and the subsequent synthesis of outputs into valuable information for Navy planners. Figure 7 illustrates the architecture guiding the flow of information, whose details are provided in the remainder of this chapter.

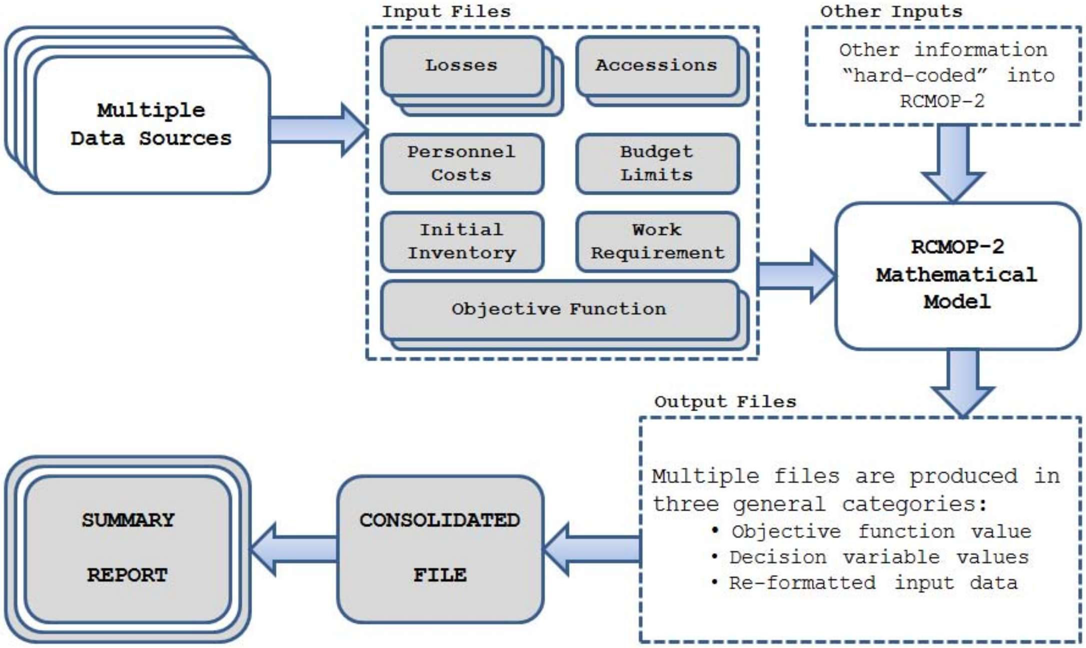

Figure 7. Information flow architecture.

A. RCMOP INPUTS

As seen in Figure 7, there are two types of inputs into our model: input files and other inputs. Each type is addressed in turn, outlining relevant data sources.

1. Losses

Three input files relate to $\alpha_{d,y}$ (our monthly loss factor): baseline loss rates, modifications to our baseline loss rates, and bounds on our loss rates.

We consider causes for "natural" losses identical to Clark [2009], and draw our loss values from the Officer Personnel Information System Data Mart via the Highlander web-based interface [Peak Software, 2009]. Specifically, our loss rates are derived from FYs 2006-08, in an effort to capture trends in recent history and have a sufficient quantity of historical data. FY 2009 data has not been used (despite recent availability) to facilitate comparison of RCMOP-2 and RCMOP as tested by Clark.

Rank is not used to specify loss rates due to how this database accounts for losses (e.g., a promotion is characterized as a "loss" to a rank, though for our purposes, we considered it as a personnel exchange). This implies that loss rates are assumed constant across ranks for a given community and YCS. The estimated annual loss rates summarized in Table 6 are considered our baseline loss rates.

Our second topic addresses changes to this baseline loss rate. Deviating from RCMOP, we abandon the premise that loss rates remain constant over the modeling time frame. As a preliminary investigation into the impact of different loss rates, we modify baseline loss rates (Table 6) by taking a "reasonable" scalar multiple of the entire table. This implies that loss rates are changed proportionally across ranks and YCS, but it is not intended to capture the impact of policy changes designed to influence certain groups (such as by designator, YCS, or both). Specific changes to baseline loss rates are discussed further in Section IV.C. *Note:* The RCMOP-2 model converts annual loss rates into monthly loss rates internally.

The final aspect of loss rates addresses limiting the loss rates, when necessary. YCS appears to have significant impact on loss rates, and we capture this relationship through a more refined upper bound on loss rates. After gathering historical data similar to our baseline loss, we consider non-overlapping three year average loss rates between FY 1976 and FY 2005 (e.g., FYs 1976-78, FYs 1979-81, … , FYs 2003-05). From this data we construct a notional "highest loss" scenario for every designator by using the highest observed loss rate for each YCS; for instance, the "highest loss" for surface warfare officers may be built as follows: "highest loss for YCS 0" occurs during FYs 1976-78, "highest loss for YCS 1" occurs during FYs 1982-84, etc. Because the historical observations include the significant force reductions required by the 1991

Defense Authorization Act [Durso et. al, 1995], we inflate our "highest loss" scenarios by a modest 25% and use these values as a refined upper bound on losses. Our methodology creates potential for loss rates to theoretically exceed 100%, in which case we limit the loss rate to exactly 100%.

YCS	INTEL	RL-OTHER	CEC	SUPPLY	AVIAT	URL-OTHER	SPEC	SUB	SWO
0	0.5%	1.0%	0.5%	1.7%	1.8%	50.0%	5.9%	0.7%	1.2%
1	0.9%	1.0%	1.5%	1.8%	2.3%	0.0%	3.1%	1.6%	2.5%
2	1.2%	1.1%	1.0%	2.0%	1.3%	0.0%	1.6%	1.7%	2.6%
3	5.8%	8.6%	9.4%	5.8%	1.6%	0.0%	1.6%	1.6%	7.4%
4	7.6%	9.4%	10.4%	6.7%	2.1%	0.0%	6.1%	11.4%	10.9%
5	4.6%	3.4%	7.4%	7.7%	0.9%	100.0%	4.6%	14.4%	12.7%
6	4.5%	4.0%	8.1%	3.9%	1.9%	0.0%	4.5%	20.1%	13.8%
7	6.1%	3.8%	5.3%	7.7%	9.2%	0.0%	6.3%	15.6%	4.4%
8	5.2%	3.4%	7.6%	6.9%	17.8%	0.0%	5.6%	5.2%	3.9%
9	5.5%	13.6%	9.9%	10.1%	12.8%	0.0%	12.6%	5.1%	6.1%
10	6.4%	11.3%	8.5%	2.7%	11.6%	0.0%	7.0%	6.6%	7.9%
11	11.6%	8.0%	4.3%	6.1%	4.9%	0.0%	13.1%	6.9%	7.2%
12	9.8%	6.6%	5.6%	6.8%	3.1%	0.0%	2.7%	6.9%	4.8%
13	2.3%	5.8%	5.5%	4.6%	3.8%	20.0%	2.6%	3.2%	2.7%
14	1.2%	4.0%	1.9%	2.5%	2.0%	20.0%	1.4%	3.6%	1.6%
15	2.8%	4.5%	3.8%	6.9%	2.8%	0.0%	0.0%	4.8%	2.9%
16	0.8%	3.2%	4.0%	2.8%	2.2%	18.8%	2.6%	2.2%	1.4%
17	1.4%	4.0%	9.9%	5.7%	4.0%	15.0%	0.0%	7.4%	3.0%
18	5.7%	9.7%	13.1%	11.7%	7.4%	40.7%	4.6%	7.5%	6.1%
19	26.8%	28.1%	38.0%	30.4%	29.7%	63.3%	28.8%	19.2%	23.8%
20	6.8%	16.8%	18.8%	14.4%	12.3%	18.8%	13.0%	6.5%	11.1%
21	4.9%	9.9%	16.1%	9.4%	12.3%	20.0%	5.1%	9.8%	11.0%
22	8.2%	12.6%	10.7%	16.8%	12.0%	15.4%	7.9%	9.9%	9.1%
23	30.0%	12.7%	22.4%	20.0%	11.2%	20.0%	8.1%	7.8%	11.2%
24	13.9%	24.9%	29.7%	17.4%	15.3%	27.3%	20.0%	10.9%	13.0%
25	20.7%	23.6%	23.1%	23.2%	24.7%	20.8%	28.1%	17.5%	19.9%
26	9.1%	26.9%	13.3%	29.8%	22.8%	16.7%	20.0%	23.1%	21.9%
27	31.3%	28.6%	15.4%	27.8%	26.5%	16.7%	18.2%	9.7%	24.5%
28	57.1%	33.3%	28.6%	28.0%	31.9%	37.5%	23.1%	32.6%	29.4%
29	60.0%	65.0%	60.0%	50.0%	46.6%	66.7%	63.6%	25.0%	29.6%
30	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	0.0%	50.0%	22.2%

Table 6. Estimates of annual natural loss rates by YCS and designator in our baseline year.

2. Accessions

Accession data comes directly from the annual strength and planning guidance given to all accession sources [CNP 2008]. These sources include Naval Academy, NROTC, OCS, and Seaman to Admiral 21 commissioning programs. The first two are captured in $accessNAROTC_{r,d,y,t}$, while the latter pair comprises $accessOCS_{r,d,y,t}$, and are shown in Table 7. Navy guidance provides maximum and minimum estimates for each designator; RCMOP-2 utilizes the mean of this range as a point estimate for input data.

	Projected monthly OCS/Seaman to Admiral 21 accessions							
	SWO	**SUB**	**SPEC**	**AVIAT**	**INTEL**	**RL.OTHER**	**SUPPLY**	**CEC**
FY 2009	25	11	2	33	3	3	11	4
FY 2010	29	11	2	34	3	4	12	5
FY 2011	30	11	2	34	4	4	12	5
FY 2012	29	11	2	34	3	4	12	5

	Projected annual USNA/NROTC accessions							
	SWO	**SUB**	**SPEC**	**AVIAT**	**INTEL**	**RL.OTHER**	**SUPPLY**	**CEC**
May 2009	522	270	72	596	13	21	10	9
May 2010	478	279	78	570	14	17	6	11
May 2011	534	279	77	633	4	18	6	11
May 2012	542	279	77	632	13	16	7	10

Table 7. Upper table: Projected monthly accessions for OCS (which are constant for each FY). Lower table: Projected accessions for USNA/NROTC (occurring annually in May).

Note: $accessOCS_{r,d,y,t}$ (Table 7) refers to input data, while $ACCESSOCS_{r,d,y,t}$ is a decision variable within the model and is further discussed later in this chapter.

3. Initial Personnel Inventory and Work Requirements

Values for initial inventory ($invent0_{r,d,y}$) and work requirements ($req_{r,j,t}$) are taken from the Total Force Manpower Management System (TFMMS) database, the principal Navy database tracking personnel and billets [CNO 2007]. Inventory data depicts the Navy as of October 1, 2008. Requirements data is available *only* by FY. If work requirements remain constant over a given FY, the model would behave unrealistically, and present usually large gains, losses, and exchanges every September in an effort to meet the new requirement for the following FY. As a result, monthly requirements are interpolated between consecutive FY's, incrementally changing requirements to reflect the increase (or decrease) needed between any two FY's.

The TFFMS database contains actual billet and personnel designator codes found in the NOC. Mapping these numerical codes to the aggregated types used by RCMOP-2 is both a critical and time consuming pre-processing task.

4. Cost and Budget Data

Personnel costs ($cost_{r,y,t}$) essentially monetizes the current inventory. Monthly officer costs are derived from multiple sources, including the Defense Finance and Accounting Service, DoN budget estimates, Navy Center for Cost Analysis (NCCA), and sponsor-supplied cost element data for FY 2008.

Our input parameter, $cost_{r,y,t}$, is based on basic allowance for subsistence (BAS), basic allowance for housing (BAH), overseas housing allowance (OHA), federal insurance contributions act (FICA), and retired pay accrual (RPA). Monthly officer costs are found by calculating the sum of basic pay, average housing allowance (including BAH and OHA), BAS, FICA, and RPA for an officer of a specific rank and years of service in October 2008. Subsequent monthly values in 2008 are identical, and an appropriate inflation index allows propagation of these values into future years.

Similarly, budget estimates ($budget_f$) are derived from the sum of the products of work requirements ($req_{r,j,t}$) and the cost elements of the work requirements within a given FY. These costs are derived from the PR for FY 2011 manpower programming rates and use equivalent cost elements as monthly officer costs [Ferguson 2008]. Explicit rates exist for FY 2011 and FY 2012, and through application of appropriate NCCA inflation indices, rates for FY 2009 and FY 2010 may be derived. Budget estimates utilized in RCMOP-2 and associated data are shown in Table 8.

	FY 2009		*FY 2010*		*FY 2011*		*FY 2012*	
	Program Rates	**Billets Required**	**Program Rates**	**Billets Required**	**Program Rates**	**Billets Required**	**Program Rates**	**Billets Required**
O1	$ 68,979	3925	$ 71,296	3995	$ 73,690	4055	$ 77,649	4051
O2	$ 88,478	4951	$ 91,449	4728	$ 94,520	4725	$ 99,654	4733
O3	$ 109,380	10160	$ 113,053	10103	$ 116,850	10141	$ 123,237	10150
O4	$ 131,687	7065	$ 136,109	7038	$ 140,680	7014	$ 148,423	7024
O5	$ 153,004	4883	$ 158,142	4874	$ 163,453	4868	$ 172,494	4870
O6	$ 182,148	2138	$ 188,265	2137	$ 194,587	2131	$ 205,338	2129
Budget	**$ 3,887,014,476**		**$ 3,990,421,637**		**$ 4,127,479,421**		**$ 4,356,807,565**	

Table 8. Estimated programming rates and modeled budget amounts for FYs 2009-12.

The similar cost elements between $\mathtt{cost}_{r,y,t}$ and $budget_f$ form a sound basis for comparison. *Note:* Details regarding the calculation of "average housing allowance," FICA, and RPA are omitted here, and can be found in the Clark [2009, pp. 61-64].

5. Objective Function Parameters

The baseline penalties assigned to specific jobs (w_j) are given in Table 9. Values are consistent with Clark [2009], but bear the same caveat: weights are for testing purposes *only* and are derived neither from any specific data source, nor guidance from the Navy.

Work Requirement	Weight
jSUB	100
jSPEC	100
jSWO	75
jAVIAT	75
jURL.OTHER	50
jINTEL	50
jRL.OTHER	50
jSUPPLY	50
jCEC	50
j1000	25

Table 9. Baseline penalty weights by work requirement.

Values for a fraction (up to l_k) of unfilled jobs within bracket *k* are likewise not driven by an empirical source, and remain static for testing purposes in RCMOP-2. Table 10 outlines the five partitions used, *k* = 1 … 5, and associated population brackets. *Note*: Figures 5-6 and associated discussion in Section II.C are germane to the relationship between weights and population segments.

Segment (*k*)	l_k	Population Bracket
1	10%	0 - 10%
2	10%	10 - 20%
3	10%	20 - 30%
4	20%	30 - 50%
5	50%	50 - 100%

Table 10. Segments, fractional segment lengths, and associated populations.

6. "Hard-coded" Inputs into RCMOP-2

This section details parameters used by the model that are found internal to the programming code implementing RCMOP-2. These inputs could still be modified, but are not brought in from an external file in the current implementation.

Specifically: $minOCS$ and $maxOCS$ are set at 0.5 and 1.25 respectively, and permit RCMOP-2 some flexibility in choosing $ACCESSOCS_{r,d,y,t}$ (as a decision variable) to be between 50% and 125% of the planned OCS accessions ($accessOCS_{r,d,y,t}$) for a given month. Additionally, we limit the quantity of officers (for a given rank and designator) allowed to fill jobs "one rank up and one rank down" at 5%. $\beta_{r,d}$ is implicitly the remaining 95%. The penalty coefficient, γ_k, is a user input as a function of *k*, and is further detailed in Section IV.B. Finally, the fraction of work requirement that may remain unmet (i.e., unfilled jobs) for a given rank is unconstrained in all of our scenarios, leaving $\eta_{r,j}$ = 1.00.

B. FUSION OF OUTPUT FILES PRODUCED BY RCMOP-2

The user has significant purview over the files produced by RCMOP-2, and the current implementation produces ten different output files. Some of these files contain "new" information, such as the value of the objective function, or values of decision variables (e.g., $FILL_{r,r',d,j,t}$). Others rework "old" information such as work requirements ($req_{r,j,t}$), modifying the structure of the data into a revised format. Aside from the value of the objective function, the raw files produced by RCMOP-2 provide little immediate insight and require substantial effort for interpretation.

C. DATA FUSION AND SYNTHESIS

Examining multiple sets of RCMOP-2 outputs, each requiring significant post-processing, is time prohibitive and prone to a myriad of opportunities for human error. This realization has led to development of a fusion tool that consolidates all raw files produced into a single file, in order to speed and ease analysis, as well as to reduce the likelihood of operator error.

The pace of exploratory analysis has improved following the creation of a single-source data file using the fusion tool. Expecting to repeat the analysis on multiple runs of the RCMOP-2 model has been a critical factor in developing a second tool, the summary tool, as a way to rapidly and consistently synthesize fused data in multiple runs.

1. Fusion Tool

The various text files produced by RCMOP-2 are in a generally similar matrix structure, where the indices for a given decision variable/parameter (DV/p) are found in the left columns and the values of the DV/p in the right columns.

The fusion tool is developed in Microsoft® Visual Basic 6.5, Version 1020 and uses Microsoft® Office Excel® 2007. The user provides a path to a folder containing all raw files produced by RCMOP-2 and a listing of these files. The fusion tool iteratively opens the listed files and moves the columnar information from the raw output files into a consolidated data file. The fusion tool creates a larger matrix with all desired information, with appropriate indices to the left and corresponding DV/p values to the right. Not every index is needed for every DV/p, resulting in a relatively sparse matrix. An outline of the consolidated matrix created by the fusion tool is depicted in Table 11.

Indices *(7 columns)*							**Decision Variable / Parameter**	
r	**r'**	**d**	**d'**	**y**	**j**	**t**		
r	r'	d			j	t	$FILL$	*(in column 8)*
r		d		y		t	HYT	*(in column 9)*
r		d		y		t	$INVENT$, $NLOSS$, $FLOSS$, $OCSACCESS$	*(in columns 10-13)*
r		d		y		t	$PROM$	*(in column 14)*
r		d	d'	y		t	$PROMTRF$	*(in column 15)*
r					j	t	req , $SURPLUS$, $\sum_k KDEFICIT$	*(in columns 16-18)*
r		d	d'	y		t	TRF	*(in column 19)*

Table 11. Consolidated data matrix.

One critical piece of user input is the way in which a specific raw output file is mapped to the consolidated file. For instance, the raw $FILL_{r,r',d,j,t}$ file contains six columns. The first five are indices (*r, r', d, j, t*) and the sixth contains the value of $FILL_{r,r',d,j,t}$. We transfer the data in the first three columns of the raw file (e.g., *r, r'*, *d*) to the first three columns of the consolidated file. The remaining data in the raw file (three columns) is moved into the columns six through eight of the consolidated file.

The fusion tool is generalized to a large degree and would need only minor modifications if the mapping to the consolidated file changed (i.e., if raw output files were added/removed).

2. Summary Tool

The fusion of data speeds subsequent analysis. This process is further expedited through the "summary tool" especially developed for this research. This tool is also implemented using the abovementioned Microsoft® products. Single-source data enables us to leverage the pivot table feature of Excel® 2007, allowing manipulation of the *view* of a data set, *without modifying the underlying data*. The summary tool captures a series of pivot table manipulations and produces preliminary analysis report for a given data set, which may be replicated on another data set. Consistent reporting between differing data sets improves both the quality and speed of subsequent analysis.

Given a single set of outputs from RCMOP-2, the fusion and summary tools can be sequentially employed to produce a preliminary summary in roughly 5-10 minutes. These initial reports, originally intended as internal documents, remain somewhat unpolished and are presented in Figures 8-10.

Each summary contains:

- Value of the objective function, unfilled jobs, and penalty type,
- Balance of flow for the modeled time-frame,
- Modeled cost and budget data for each FY,
- Deficit analysis charts examining officer shortfalls:
  - for selected communities,
  - as a percentage of required billets, and
  - aggregated over FYs and ranks.
- Plots of $req_{r,j,t}$, $INVENT_{r,d,y,t}$, and "met" requirements over time for:
  - the entire modeled population,
  - each rank, and
  - each designator.
- Preliminary numerical analysis of:
  - $FLOSS_{r,d,y,t}$ and $HYT_{r,d,y,t}$,
  - $TRF_{r,d,d',y,t}$ and $PROMTRF_{r,d,d',y,t}$, and
  - $PROM_{r,d,y,t}$ and $PROMTRF_{r,d,d',y,t}$.
- Administrative data (such as file path and name)

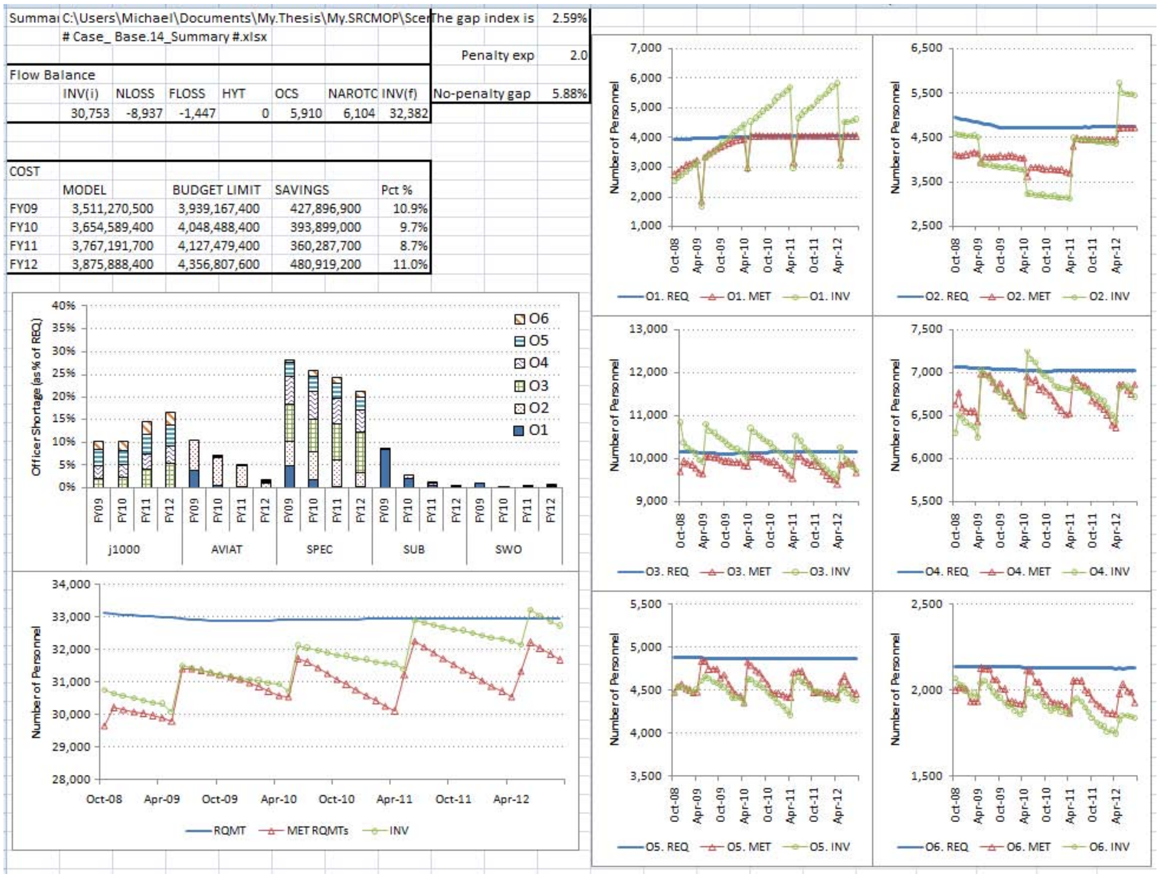

Figure 8. First summary report screen capture.

In Figure 8, the upper left box reports administrative information. Immediately below is the balance of flow for this scenario. To the right of these boxes, the objective function value, type of penalty employed, and percentage of jobs vacant are recorded. The third box down on the left contains a summary of financial information. The bar graph illustrates our initial analysis of unfilled billets.

The remaining graphs show the relationships between billet requirements (".REQ"), personnel inventory (".INV"), and the number of requirements being satisfied (".MET"). The larger line graph (bottom left) is for the entire modeled population, while the six smaller charts on the right make the same comparisons aggregated by rank.

Forced and HYT Losses

		O1	O2	O3	O4	O5	O6	Grand Total
RL_INTE	FLO	13	0	0	35	27	18	93
	HYT	0	0	0	0	0	0	0
RL_OTH	FLO	19	0	0	92	44	54	210
	HYT	0	0	0	0	0	0	0
STF_CEC	FLO	244	0	0	2	0	5	251
	HYT	0	0	0	0	0	0	0
STF_SUF	FLO	473	189	5	55	11	144	877
	HYT	0	0	0	0	0	0	0
U.AVIAT	FLO	0	0	0	0	0	0	0
	HYT	0	0	0	0	0	0	0
U.OTH	FLO	0	0	0	3	4	10	16
	HYT	0	0	0	0	0	0	0
U.SPEC	FLO	0	0	0	0	0	0	0
	HYT	0	0	0	0	0	0	0
U.SUB	FLO	0	0	0	0	0	0	0
	HYT	0	0	0	0	0	0	0
U.SWO	FLO	0	0	0	0	0	0	0
	HYT	0	0	0	0	0	0	0
Total FLO		750	189	5	187	86	230	1,447
Total HYT		0	0	0	0	0	0	0

End Effects?	
y1204	0
y1205	396
y1206	119
y1207	81
y1208	94
y1209	254
total	944

TRANSFERS

	FROM						
	U.AVIAT	U.OTH	U.SPEC	U.SUB	U.SWO	Total TF	Total PRTR
O1	145	0	0	130	1,345	1,620	0
O2	0	0	0	28	82	98	12
O3	1,415	0	0	396	1,385	3,196	0
O4	82	0	4	24	91	200	0
O5	1,059	0	0	14	421	1,411	82
O6	344	0	5	74	160	580	4
Grand T	3,045	0	9	665	3,483	7,105	98

	FROM				
TO	U.AVIAT	U.SPEC	U.SUB	U.SWO	Total TRF
RL_INTE	2,028	0	46	854	2,928
RL_OTH	725	0	352	1,732	2,809
STF_CEC	35	0	116	432	584
STF_SUF	257	9	150	466	882
Grand T	3,045	9	665	3,483	7,202

End Effects?		
y1204	18	0
y1205	448	0
y1206	391	0
y1207	117	0
y1208	66	0
y1209	49	0
Last Six	1,088	0

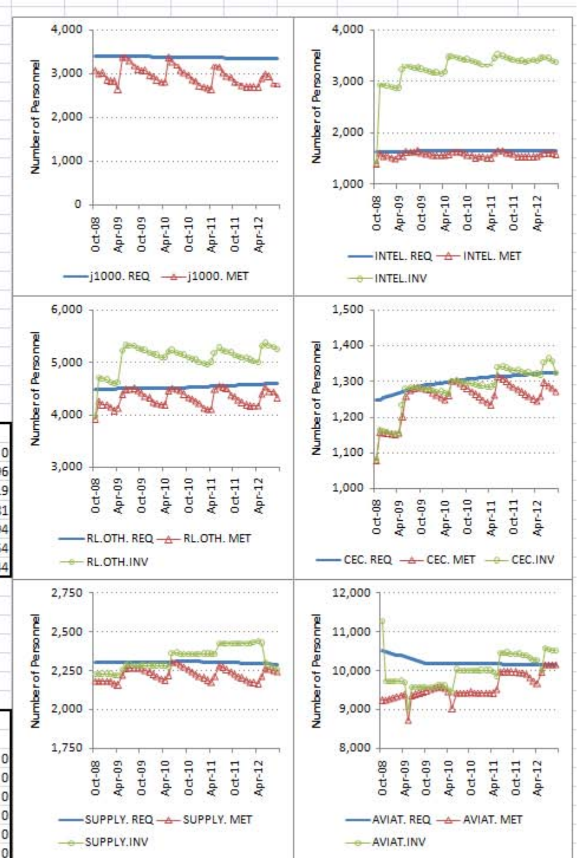

Figure 9. Second summary report screen capture.

Figure 9 contains preliminary analysis on forced and HYT losses in the upper left, while examination of transfers (using different aggregations) are displayed in the lower left. The remaining figures are a continuation of the smaller charts previously described in Figure 8 (e.g., requirements, inventory, and met requirements) though these are aggregated by billet type rather than by rank. Only six of the ten billet aggregations are shown here, with the remaining four appearing in Figure 10. The remaining information on the left portion of Figure 10 is promotion analysis aggregated by rank and FY.

PROMOTIONS					
FY09 PROMOTIONS					
	O2	O3	O4	O5	O6
Promote	1,624	2,226	1,934	1,020	341
Eligible	1,627	2,235	2,127	1,033	877
Rate	99.8%	99.6%	90.9%	98.8%	38.9%
AVG YCS			9.1	15.6	21.2
FY10 PROMOTIONS					
	O2	O3	O4	O5	O6
Promote	1,633	2,167	1,513	840	414
Eligible	1,636	2,175	2,267	1,190	948
Rate	99.8%	99.6%	66.8%	70.6%	43.7%
AVG YCS			9.4	15.3	21.8
FY09 PROMOTIONS					
	O2	O3	O4	O5	O6
Promote	2,873	1,525	1,069	880	381
Eligible	2,908	1,566	2,337	1,425	1,022
Rate	98.8%	97.4%	45.8%	61.8%	37.3%
AVG YCS			9.6	15.2	21.9
FY10 PROMOTIONS					
	O2	O3	O4	O5	O6
Promote	2,879	1,529	1,489	856	519
Eligible	2,914	1,572	2,800	1,336	1,070
Rate	98.8%	97.3%	53.2%	64.1%	48.5%
AVG YCS			9.6	15.4	21.3

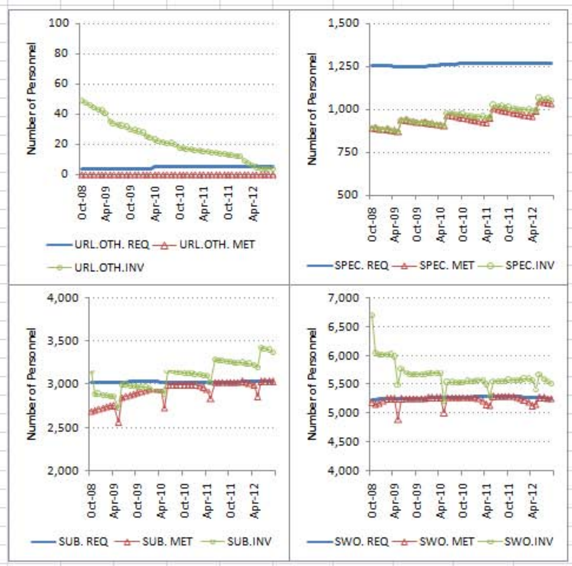

Figure 10. Third summary report screen capture.

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IV. RESULTS AND ANALYSIS

This chapter reports our results and analysis methodology. We compare linear and non-linear penalties in RCMOP-2, and explore scenarios of plausible loss rates.

We solve RCMOP-2 on a laptop computer at 2.6 GHz with 3.5 Gb of RAM, running Windows XP™. The model is implemented and generated using the General Algebraic Modeling Language [GAMS Development Corporation 2010], and we solve it using Newton's barrier method within CPLEX and default settings [GAMS/CPLEX , 2010]. A typical instance of RCMOP-2 has approximately 56,000 continuous variables and 193,000 constraints, and solves to optimality in approximately one minute.

A. MEETING REQUIREMENTS

An important part of our discussion in this chapter concerns the quantity of billets filled. When determining this number, it is essential to understand the interaction between the *INVENTORY* and *FILL* decision variables and the *req* parameter in equations (6) - (7). For example, Figure 11 illustrates the concept of a billet requirements being "met" at the O2 level. While the planning month, YCS, job type, and designator are tracked within the model, for simplicity they are omitted from the figure and subsequent discussion.

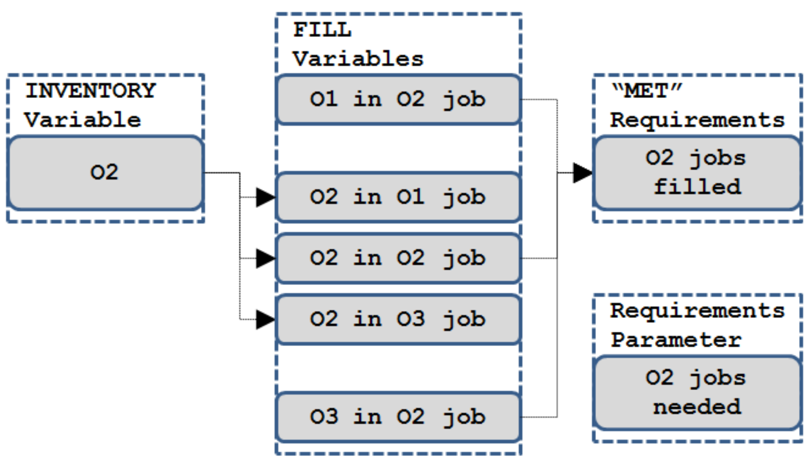


Figure 11. Interaction of decision variables and parameters in determining quantity of requirements being satisfied.

A notional inventory of O2 personnel may fill billets at the O1 through O3 level. We use the parameter $\beta_{r,d}$ to limit the number of r = O2 personnel assigned to non-O2 billets in designator d. For example, 95% of O2's must fill an O2 billet. When looking at the number of O2 billets filled, we must consider O1, O2, and O3 personnel who may be assigned to an O2 billet. The sum of these personnel is the number of O2 billet requirements being "met." A simple ratio of "met" requirements versus the requirement parameter of O2 billets yield the fraction of billet requirements that are satisfied. This new metric is used throughout this chapter. *Remark*: We note that, in the current formulation of RCMOP-2, $\beta_{r,d}$ only guarantees that a fraction of at least $\beta_{O2,d}$ personnel will be performing O2 jobs. But, it does not ensure that a fraction of O2 jobs will be done by O2 personnel. For instance, in Figure 11, $\beta_{O2,d}$ is graphically represented by the connection between variables "O2" `INVENTORY` and "O2 in O2 job" `FILL`. It is the only connection that is constrained in our model.

B. RCMOP-2 RESULTS

1. Data Fidelity

We have made significant efforts to replicate many elements of Clark's work for RCMOP-2. We acknowledge that there are minute differences: cost and budget inputs are premised, in part, on NCCA inflation indices, accessions plans are promulgated annually—in these cases, we use more recent guidance, which is not significantly different. The largest differences are found in the FY budget constraints, where our values are roughly 1.3% higher than earlier estimates. In neither Clark's nor this work do budgets estimates become a binding constraint.

Through the addition of more personnel designators and corresponding billet types over a nearly identical starting inventory, RCMOP-2 implicitly places additional constraints than those in RCMOP. We expect slightly differing results than those seen in RCMOP due to additional resolution and increasing the time horizon from two to four years.

In order to replicate RCMOP's linear objective function, we employ a linear penalty function (i.e., a unique segment $k = 1, \gamma_1 = 1$).

In RCMOP, the *OTHER* personnel designator included 8,846 officers who were essentially uncharacterized. In RCMOP-2, these same 8,846 officers are categorized as *INTEL*, *SUPPLY*, *CEC*, and *RL-OTHER*. This final group, *RL-OTHER*, contains 4,052 personnel who remain essentially uncharacterized, and represent approximately 45% of the 8,846 officers who were previously uncharacterized in RCMOP.

Figure 12. RCMOP-2 results examining billet requirements, satisfied billet requirements and personnel inventories of four new designators in RCMOP-2 with a linear penalty.

In Figure 12, we see billet requirements, met requirements, and personnel inventory for *INTEL*, *SUPPLY*, *CEC*, and *RL-OTHER* billet designators in RCMOP-2. The met requirements and billet requirements curves are nearly indistinguishable, indicating each individual community is adequately filling jobs from their personnel inventory. The large spike late in the modeling horizon in an otherwise stable *RL-OTHER* inventory raises concern over end effects [Brown et al., 2004]. This conclusion could not be reached in RCMOP because excess personnel in one community may fill shortages in others as a result of the broader aggregation of those communities into the *OTHER* community of that model.

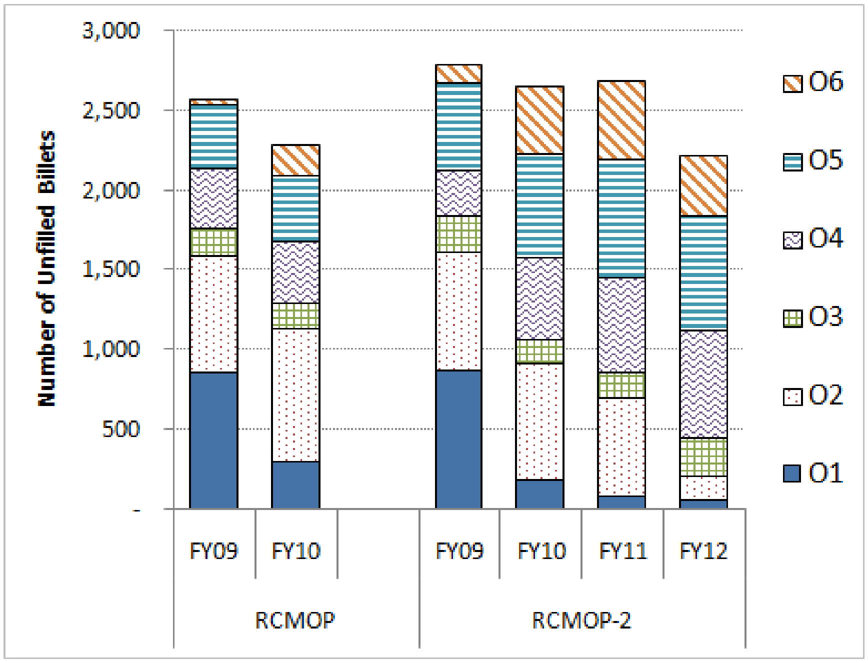


Figure 13. RCMOP and RCMOP-2 results: Unfilled billets by rank and FYs over respective two- and four-year time horizons.

Figure 13 compares billet vacancies, aggregated by FY and rank between RCMOP and RCMOP-2, and illustrates both fidelity effects and the impact of extending the modeling horizon. Recall that in RCMOP-2, the *SUPPLY* and *CEC* officers are ineligible to fill *j1000* billets (Figure 3), while they are permitted to do so in RCMOP. Using the initial inventory, this effectively removes 3,379 officers (i.e., 10% of the total personnel inventory) from consideration for *j1000* billets. In Figure 13, RCMOP-2 typically has a larger number of shortages in the ranks O4 through O6 than RCMOP, which drives the total billet shortfall higher in RCMOP-2 when comparing equivalent FYs between the two models. Also, the total shortage trends lower over time in both models, as expected.

Impacts of the increased time horizon are also seen in Figure 13 and relate to the flow of personnel. In reality, officers spend two years in both the O1 and O2 ranks, but due to our YCS advancement assumption, which is identical in RCMOP, this is not always the case. RCMOP's 24-month horizon allows accessions in the first seven months (which excludes any larger numbers of May accessions) to reach the rank of O2, and is inadequate for any new accessions to progress to the rank of O3. In contrast, accessions in the first 31 months of RCMOP-2 may reach the rank of O2 (and includes two larger May accession groups). It is even possible for those commissioned in the first seven months of RCMOP-2 to reach the rank of O3. Comparing the behaviors of the O1 and O2 populations over time between the two models illustrates this (Figure 13). In RCMOP, O1s and O2s initially contribute 62% of the annual billet shortage, which decreases to 56% in the second and final year of the model. In RCMOP-2, the same population accounts for 58% in the first year, and by the fourth year, this figure is reduced to 9% of the annual billet vacancies. This behavior is expected, since our personnel flow is inherently time dependent. Increasing the time horizon allows both greater numbers of personnel flow (i.e., total flow volume will be higher), and for these greater numbers to matriculate further into the existing rank structure.

2. Comparison of Linear and Non-linear Penalties

This section examines RCMOP-2 outputs when the values for γ_k are modified, creating different non-linear penalties. In our examples, we set $\gamma_k = k^{x-1}$ where $x \geq 1$ is a "penalty exponent" of our choice. If $x = 1$, then $\gamma_k = 1$, for all values of k, resulting in a linear penalty. When $x > 1$, non-linear penalties increasing with k occur. For this analysis, values of $x \in \{1, 1.5, 2, 2.5\}$ are explored and results are summarized in Table 12 and Figure 14.

Item		Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Linear Penalty	*Non-linear penalties*		
1. Penalty Exponent (x)		$x = 1.0$	$x = 1.5$	$x = 2.0$	$x = 2.5$
2. Gap index		5.24%	3.79%	2.59%	1.93%
3. Percent of billets unfilled		5.99%	6.05%	5.88%	6.38%
4. FY 2009	**Budget Estimate**	\$ 3,939 million	\$ 3,939 million	\$ 3,939 million	\$ 3,939 million
	Personnel Cost	\$ 3,508 million	\$ 3,512 million	\$ 3,511 million	\$ 3.510 million
	Potential Savings	*\$ 430 million*	*\$ 427 million*	*\$ 428 million*	*\$ 429 million*
5. FY 2010	**Budget Estimate**	\$ 4,048 million	\$ 4,048 million	\$ 4,048 million	\$ 4,048 million
	Personnel Cost	\$ 3,649 million	\$ 3,654 million	\$ 3,654 million	\$ 3,649 million
	Potential Savings	*\$ 399 million*	*\$ 394 million*	*\$ 394 million*	*\$ 399 million*
6. FY 2011	**Budget Estimate**	\$ 4,127 million	\$ 4,127 million	\$ 4,127 million	\$ 4,127 million
	Personnel Cost	\$ 3,759 million	\$ 3,765 million	\$ 3,767 million	\$ 3,759 million
	Potential Savings	*\$ 367 million*	*\$ 362 million*	*\$ 360 million*	*\$ 368 million*
7. FY 2012	**Budget Estimate**	\$ 4,356 million	\$ 4,356 million	\$ 4,356 million	\$ 4,356 million
	Personnel Cost	\$ 3,865 million	\$ 3,868 million	\$ 3,876 million	\$ 3,866 million
	Potential Savings	*\$ 491 million*	*\$ 487 million*	*\$ 480 million*	*\$ 490 million*
8. Officer Flow:	**Starting Inventory**	= **30,753**	= **30,753**	= **30,753**	= **30,753**
	Natural Losses	- 8,985	- 8,946	- 8,937	- 8,967
	Forced Losses	- 1,442	- 1,499	- 1,447	- 1,935
	HYT Losses	- 0	- 0	- 0	- 0
	OCS Accessions	+ 5,910	+ 5,910	+ 5,910	+ 5,910
	USNA/ROTC Accessions	+ 6,104	+ 6,104	+ 6,104	+ 6,104
	Final Inventory	= **32,340**	= **32,322**	= **32,382**	= **31,865**

Table 12. RCMOP-2 results: Comparison of scenarios with linear and non-linear penalties. (Note: dollar amounts may not add due to rounding.)

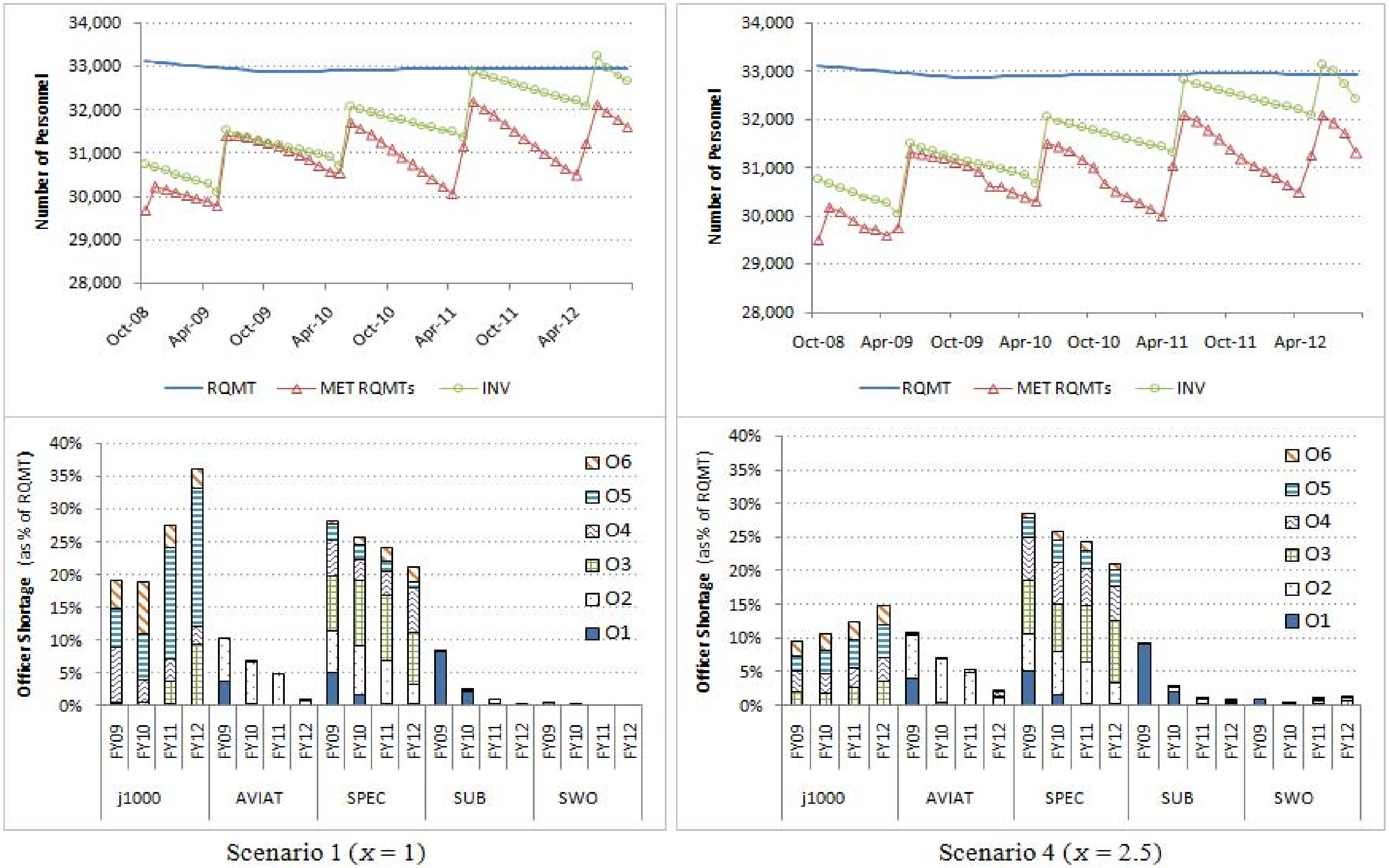


Figure 14. RCMOP-2 results: Total personnel requirements, inventory, and met requirements (upper figures), and officer shortages (as a percentage of billets required) by rank, designator, and FY (bottom figures). Left and right columns are for scenarios 1 and 4, respectively.

a. Gap Index and Unfilled Billets

Lines 1 and 2 of Table 12 suggest an inverse relationship between the penalty exponent, x, and the gap index (our objective function value). This should not be understood as results for larger values of x are necessarily better. For example, suppose the total penalty were constant between two scenarios with different values of x. As x increases, the normalizing $\overline{w}$ also increases, forcing the gap index lower. Maximum penalties are not achieved, but are necessary to normalize the gap index in each case. Hence, the gap index alone is useful for determining the optimal solution and/or performance comparison for a fixed x, but, comparisons of the gap index *for differing x (or K) values* are not immediately obvious.

Increasing the number of penalty tiers and "penalty exponent" (i.e., $|K|$ and x) causes more homogeneous losses across communities. Increases to $|K|$ and x would eventually ensure that no second billet vacancy occurs in a given community until a billet vacancy occurs in every other community.

Percentage of unfilled billets remains relatively constant at nearly 6%.

b. Personnel Costs, Budget and Potential Savings

Fiscal figures are nearly indistinguishable between scenarios, and RCMOP-2 offers roughly 8-11% cost savings in a given FY. We do note that potential savings decline over the first three FYs, and then reach their maximum value in their final FY.

c. Personnel Flow and Verification of HYT and OCS Accession Results

Balance of personnel flow is also comparable between scenarios. The HYT losses and OCS accessions merit further comment. HYT losses are zero for these four scenarios. In fact, HYT losses have remained zero in each of the scenarios run in this research. As an excursion to verify that this was only the result of multiple optimal solutions, a modest penalty was added to the $FLOSS_{r,d,y,t}$ decision variable and added to a test objective function. Results from this excursion model had reduced (and non-zero) values for $FLOSS_{r,d,y,t}$ and slightly increased values for $HYT_{r,d,y,t}$. In other words, RCMOP-2 uses $FLOSS_{r,d,y,t}$ and $HYT_{r,d,y,t}$ semi-interchangeably: anyone eligible for HYT loss could instead be counted as a forced loss, though the converse is not true.

The second item relates to the decision variable $ACCESSOCS_{r,d,y,t}$. In every scenario run in RCMOP-2 its value remains at 5,910, which is the model's upper bound of 125% of planned OCS accessions. Again, an excursion was made modifying both the input parameters $maxOCS$ and $accessOCS_{r,d,y,t}$. This second excursion showed varying values for our decision variable $ACCESSOCS_{r,d,y,t}$ once input parameters were sufficiently increased.

d. Inventory, Requirements, Met Requirements, and Deficit Analysis

Figure 14 compares certain outputs from scenarios 1 and 4. Scenarios 2 and 3 showed similar results to the latter providing intermediate values between the two scenarios illustrated. The upper charts show the Navy-wide officer billet requirements, personnel inventory and requirements being met for each scenario. In scenario four, the met requirements curve shows more minute movement along the saw-tooth structure common to both graphs.

The gap between the inventory and met requirements curves seems to widen between June 2010 and April 2012. The slope of each curve is a rate of change in personnel per unit time, that is, these represent some form of a loss rate. The steepness of the inventory curve is being mitigated through the accession of new officers, who have not met their obligated service time and thus have lower loss rates. The slope of the met requirements curve is less steep during the first two cycles (through May 2010) due to the increased accession of new officers (e.g., excess O1s may be assigned to O2 jobs). In May 2010 the model becomes "O1 saturated" and the slope, moving forward, reflects the loss rate for personnel that O1s cannot replace in the model (e.g., O3 and above). As noted in previous discussion on loss rates, these personnel generally have higher loss rates than new accessions; for example, compare YCS < 2 and YCS > 4 from Table 6.

e. Deficit Analysis

The bottom two charts in Figure 14 show the ratio of total deficit to jobs required aggregated over each FY, for all ranks and selected designators in both scenarios. Designators selected have the largest contribution to the total deficit and, by extension, the largest impact on our objective function. Both of the lower charts show that over time the percentage deficit (by billet type) shrinks, with the exception of the `j1000` billets. Given the lower weight assigned to these billets, this is not surprising. Examining the SPEC billets, both graphs show a sizeable percentage deficit well dispersed across ranks.

Contrasting the lower figures, the shortfall in the `j1000` billets is strikingly different. The left panel, where penalties are constant (and equal to the weights), shows that the `j1000` penalty is preferred over any other penalty. For example, given a group of `SUB` officers, the model will preferentially assign them to `SUB` jobs over `j1000` jobs. The `j1000` jobs are filled *only* after the `SUB` jobs are filled (if there are excess `SUB` personnel remaining), because the penalty for unfilled `SUB` billets is always three times greater than unfilled `j1000` billets. In the scenario 1 graph, knowing that `j1000` jobs will be preferentially unfilled, the shortfalls for other designators reflect the ranks and designators where requirements exceed inventory. The right chart has significantly lower percentages associated with the `j1000` billets. Here we see the impact of non-linear penalties: as `j1000` billets are not filled, they become more and more penalized, until the cost of not filling the next `j1000` billet is greater than the penalty of another designator. We clearly see the shortage percentage declining for `j1000` billets, but not a corresponding increase in other designators. This is due to the relative sizes of each type of billet. Note: Requirements are, approximately 3,300 `j1000` billets; 3,000 `SUB` billets; 5,000 `SWO` billets; and 10,000 `AVIAT` billets. Closer inspection of the lower right chart in Figure 14 shows that for SWO billets in FY 2011 and FY 2012, there is an increase compared to the same periods for scenario 1.

f. Promotions

A summary of promotions is provided in Table 13. Promotions to the control grades (i.e., O4 – O6) may occur within a three-year window and promotion rates should fall within specific thresholds as summarized in Table 5. The calculation of promotion rates, however, is not obvious because every year some officers begin the year within a promotion zone and move out of this window due to a gain in YCS, and vice versa. Though the calculation may be slightly flawed, we still compute promotions into the three controlled officer grades annually in each of our four scenarios, yielding 48 promotion rates. Our estimate of promotions indicates that RCMOP-2 results do not remain within desired promotion rate thresholds in 28 of 48 cases, preferred “under” promoting to “over” promoting by a 3:1 ratio, and was up to 25% outside the acceptable window. This suggests that promotion rates as established by law may be insufficient to support an optimal allocation of officers to billets. By comparison, Clark [2009] reports only one case (of six) where promotions deviated from guidance in the original RCMOP model.

Examining the average YCS of individuals promoted, RCMOP-2 clearly promotes early within the promotion windows. Only once in the four scenarios does the average YCS reach the midpoint of the promotion window (Scenario 1 in FY 2010 for O6s). In Scenario 4, the 9.0 average YCS for O4s during FY 2009 suggests that, in some cases, the model may be promoting too many “below zone” personnel. Lacking a precise definition of “below zone” and not having promotion zones within the RCMOP-2 formulation, we lack the capability to further investigate this intuitive claim.

		Scenario 1					Scenario 2				
	to rank	**O2**	**O3**	**O4**	**O5**	**O6**	**O2**	**O3**	**O4**	**O5**	**O6**
FY 2009	**Promoted**	1,624	2,226	2,005	911	230	1,624	2,226	1,997	959	378
	AVG YCS	-	-	9.2	15.7	21.2	-	-	9.1	15.7	21.4
FY 2010	**Promoted**	1,633	2,167	1,560	823	400	1,633	2,167	1,492	875	418
	AVG YCS	-	-	9.5	15.4	22.0	-	-	9.4	15.2	21.7
FY 2011	**Promoted**	2,874	1,525	906	814	581	2,872	1,525	1,079	799	316
	AVG YCS	-	-	9.1	15.3	21.5	-	-	9.6	15.1	21.3
FY 2012	**Promoted**	2,879	1,528	1,261	833	629	2,879	1,512	1,442	888	566
	AVG YCS	-	-	9.6	15.5	21.6	-	-	9.2	15.1	21.3
		Scenario 3					**Scenario 4**				
	to rank	**O2**	**O3**	**O4**	**O5**	**O6**	**O2**	**O3**	**O4**	**O5**	**O6**
FY 2009	**Promoted**	1,624	2,226	1,934	1,020	341	1,624	2,226	1,946	1,125	412
	AVG YCS	-	-	9.1	15.6	21.2	-	-	9.0	15.6	21.3
FY 2010	**Promoted**	1,633	2,167	1,513	840	414	1,633	2,167	1,416	781	416
	AVG YCS	-	-	9.4	15.3	21.8	-	-	9.2	15.2	21.5
FY 2011	**Promoted**	2,873	1,525	1,069	880	381	2,873	1,525	1,179	880	369
	AVG YCS	-	-	9.6	15.2	21.9	-	-	9.7	15.2	21.7
FY 2012	**Promoted**	2,879	1,529	1,489	856	519	2,865	1,527	1,353	953	493
	AVG YCS	-	-	9.6	15.4	21.3			9.1	15.3	21.2

Table 13. RCMOP-2 results: Promotion summary.

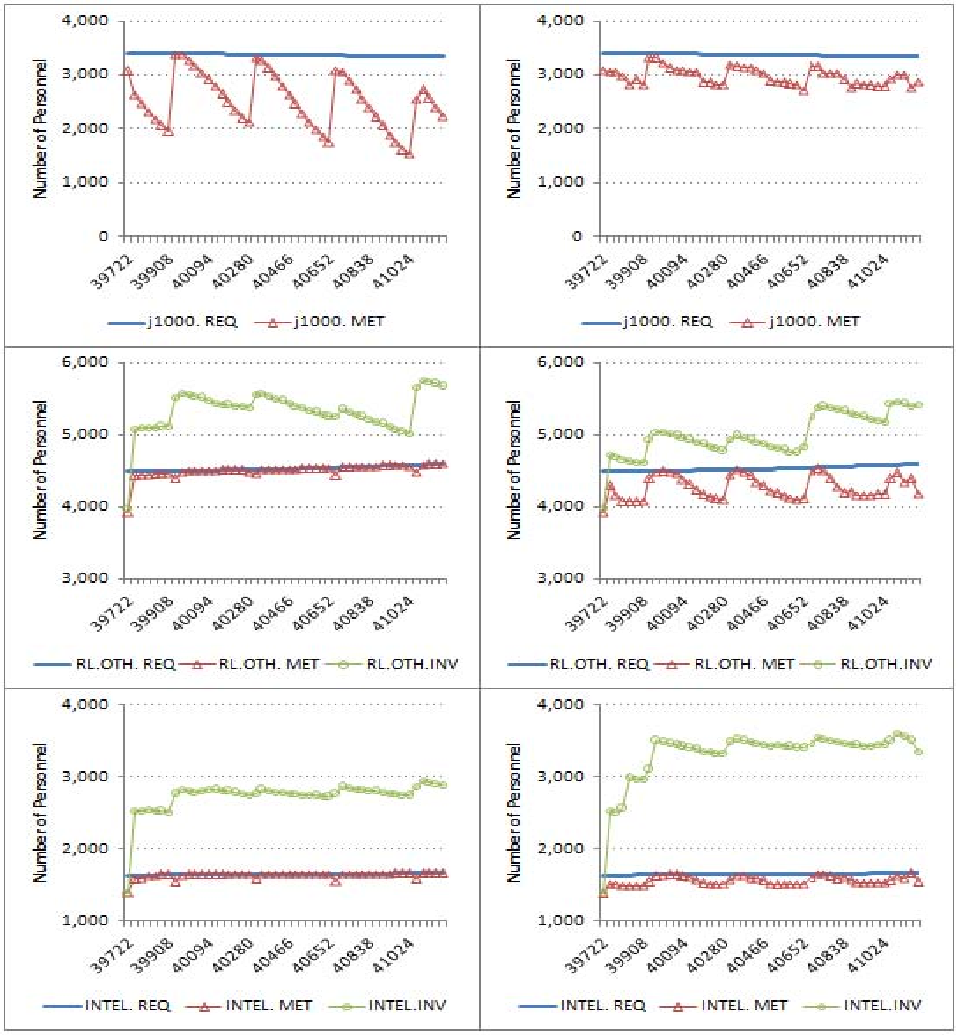
g. Transfers, Forced Losses, and End Effects

Table 14 aids our exploration of lateral transfers. We combine the $TRF_{r,d,d',y,t}$ and $PROMTRF_{r,d,d',y,t}$ decision variables in this discussion, as the latter is typically 1% of the total. For each scenario, the total quantity of officers leaving communities is comparable. However where these officers are assigned to can vary significantly, as seen in the difference between the `INTEL` totals in scenarios 1 and 4.

	From / To	INTEL	RL-OTHER	CEC	SUPPLY	Total
Scenario 1	**AVIAT**	1,392	1,176	72	321	*2,961*
	SPEC	-	-	2	7	*9*
	SUB	-	456	33	146	*635*
	SWO	711	1,658	720	590	*3,678*
	Total	*2,103*	*3,289*	*828*	*1,064*	***7,284***
Scenario 2	**AVIAT**	2,029	854	44	101	*3,027*
	SPEC	-	-	-	9	*9*
	SUB	122	432	34	70	*659*
	SWO	1,038	1,741	357	336	*3,472*
	Total	*3,189*	*3,027*	*435*	*517*	***7,168***
Scenario 3	**AVIAT**	2,028	725	35	257	*3,045*
	SPEC	-	-	-	9	*9*
	SUB	46	352	116	150	*665*
	SWO	854	1,732	432	466	*3,483*
	Total	*2,928*	*2,809*	*584*	*882*	***7,202***
Scenario 4	**AVIAT**	2,202	772	29	180	*3,183*
	SPEC	-	-	-	9	*9*
	SUB	234	331	87	50	*702*
	SWO	1,438	1,889	269	204	*3,800*
	Total	*3,874*	*2,992*	*386*	*442*	***7,694***

Table 14. RCMOP-2 results: summary of transfers in scenarios 1-4.

The model is diverting officers into `INTEL` and `RL-OTHER` when it is unable to meet a requirement with officers in their original communities. For the `INTEL` and `RL-OTHER` communities any surplus must be allocated to the `j1000` jobs in our model (Figure 3) or become part of the $SURPLUS_{r,j,t}$ variable (i.e., idle personnel). We can visually see that the excesses for these two communities provide a clear majority of the personnel filling `j1000` jobs in Figure 15. An earlier comment on the aggregation of the 1000-coded billets notes these two communities may fill *at most* 50% of the `j1000` billets.



Scenario 1 ($x = 1$) **Scenario 4 ($x = 2.5$)**

Figure 15. RCMOP-2 results for personnel inventory, work requirements, and met requirements for j1000, RL-OTHER, and INTEL billets in scenarios 1 and 4. Note: j1000 charts do not have an inventory, since these jobs are filled from multiple communities.

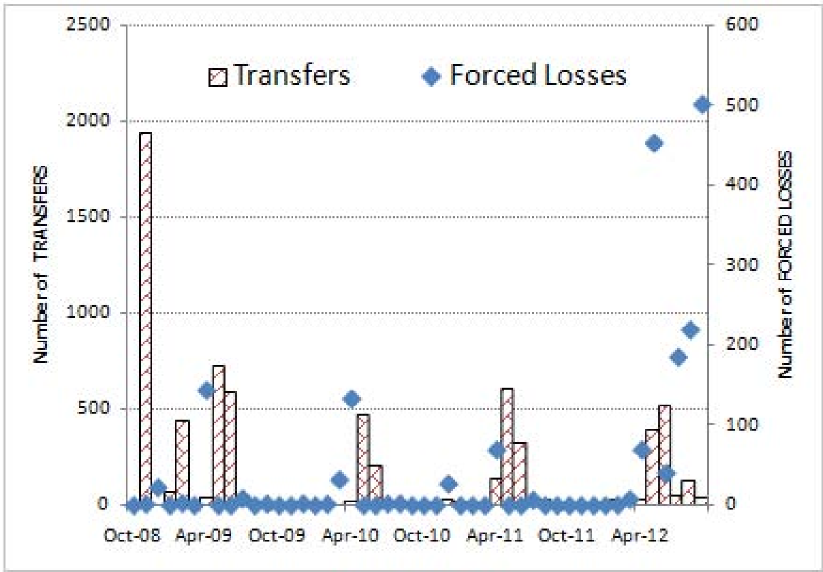
Figure 15 also displays the impact of linear and non-linear penalty weights. On the left (our linear penalty scenario), the numbers of j1000 requirements met oscillates with larger amplitude than the corresponding figure on the right. The converse is true for the two remaining pairs of charts. On the two lower left charts, met requirements are very stable (and requirements are frequently satisfied), while on the right they show more movement as RCMOP-2 works to avoid the increasing costs of not meeting j1000 billet requirements.

Forced losses for each scenario were briefly discussed as part of the personnel flow balance. We return to those values to illustrate the likelihood of end effects in our model. Comparing the number of forced losses over the entire four-year modeling horizon to those occurring in only the final 6 months (i.e., 12.5% of the time frame), the volume of forced losses clearly increases sharply during the last few months (Table 15).

	Forced Losses		
	Total over 48 months	*Total over final 6 months*	
	Quantity	**Quantity**	**Percent**
Scenario 1	1,442	940	65%
Scenario 2	1,499	971	65%
Scenario 3	1,447	944	65%
Scenario 4	1,935	1,400	72%

Table 15. Evidence of end effects in RCMOP-2: Comparison of forced losses over 48 months and the final six months for various penalty scenarios.

Though end effects appear in the model, not every decision variable is impacted by their presence. Figure 16 shows forced losses and transfers (to include concurrent promotions) over the model's horizon for scenario 4. There is a clear increase in force losses occurring late in the model's timeframe, as noted in Table 15. However, there is little evidence of end effects affecting transfers. The other three scenarios also showed clear signs of end effects impacting forced losses, and minimal support linking transfers with these effects.



Scenario 4

Figure 16. Selective sensitivity to end effects in RCMOP-2. Transfers show little impact while forced losses increase notably at the end of the modeling time horizon.

C. EXPLORING LOSS RATES

1. Generation of Loss Scenarios

In Chapter III, we discussed *how* to modify loss rates by a scalar multiple. In this section, we detail the values of these scalars used in this research. Historical loss rates are employed again, but in groups of three-year rates (Figure 17).

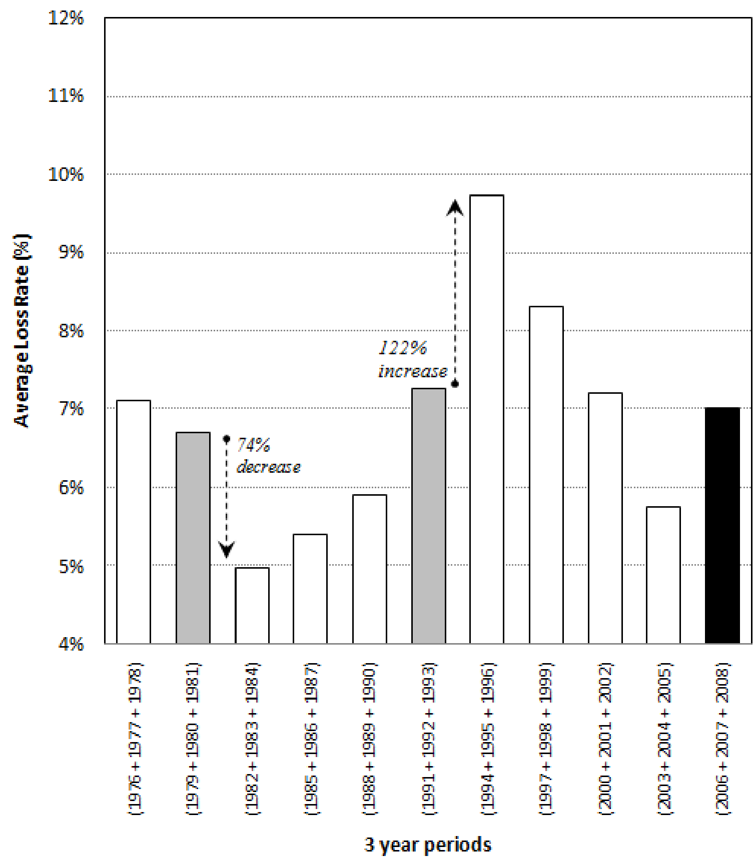


Figure 17. Historical three-year loss rates.

Given the FYs 2006-08 loss rate (*black bar* in Figure 17), other similar loss rates are identified from our observations during FYs 1979-81 and FYs 1991-93 (*grey bars*). The subsequent periods after similar observations are identified as FYs 1982-84 and FYs 1994-1996 respectively. Taking the ratio of these loss rates (later period divided by the earlier) yields a scalar that reflects the change in the loss rate from one period to the next. In Figure 17, the FYs 1982-84 loss rate may be expressed as 74% of the FYs 1979-81 loss rate. Similarly, the FYs 1994-96 value is 122% of the prior rate. We take these values as our upper and lower limit to the three-year change in rate. *Note*: other time periods (e.g., FYs 1976-78, FYs 2000-02) are similar to the FYs 2006-08 loss rate, but the ratio of subsequent years yields values between 74% and 122%.

In order to accommodate the above loss rates to the model's four-year horizon, loss rates remain unchanged for the first year and are modified annually over the following three years. For the purposes of scenario development, we assume that loss rates either increase (*i*) or decrease (*d*) as the model moves from one FY to the next. This provides eight unique scenarios. Note: Although the three-year averages appear the same in some of the scenarios, the *order* of increases and decreases to the baseline loss rate is different.

We include a baseline scenario in which loss rates do not change, as illustrated in Figure 18. This scenario is identical to scenario 3 from Section B. Henceforth, we shall refer to the highest and lowest loss scenarios (upper and lower branches in Figure 18) as High and Low scenarios, respectively.

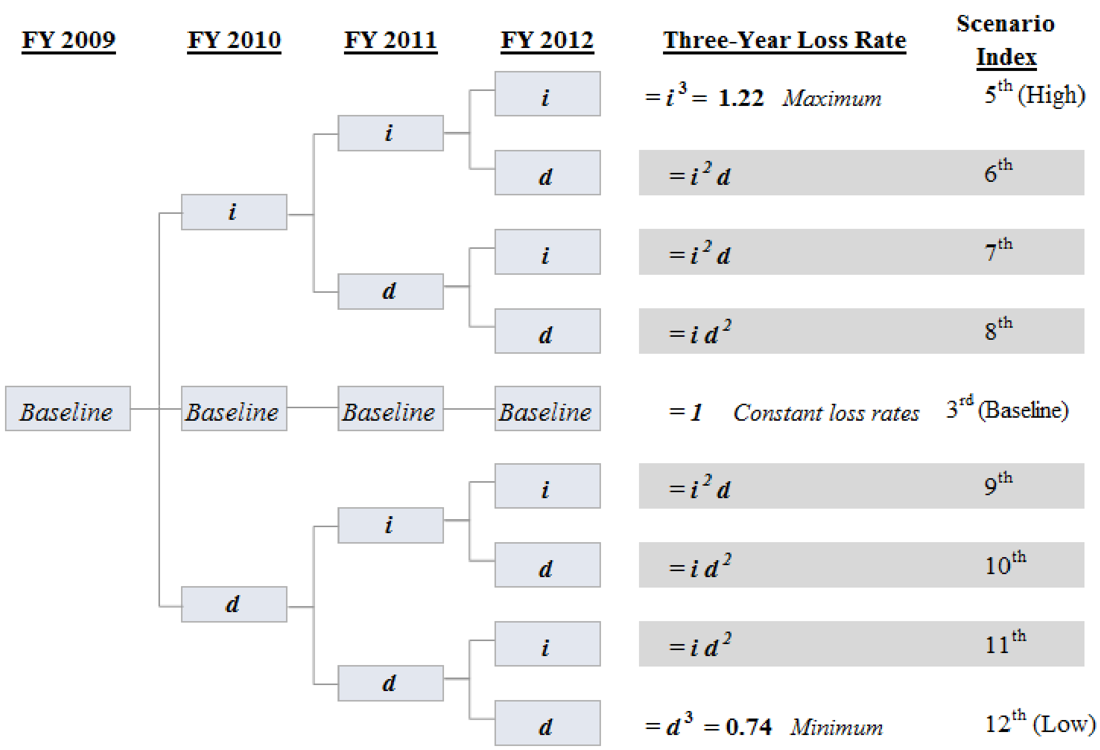


Figure 18. Increases (*i*) and decreases (*d*) applied to baseline loss rate over four years to develop loss scenarios.

2. Results Overview for Loss Scenarios

This portion of our research reports the results of the loss scenarios outlined in the previous paragraph. We employ non-linear penalties in these analyses and fix our "penalty exponent" at $x = 2$ (to be comparable with baseline scenario 3).

Figure 19 shows the values of the gap index, percentage of unfilled billets, and quantity of natural losses in the respective scenarios. Scenarios High and Low consistently represent the extreme values with the baseline case falling roughly about half way in-between.

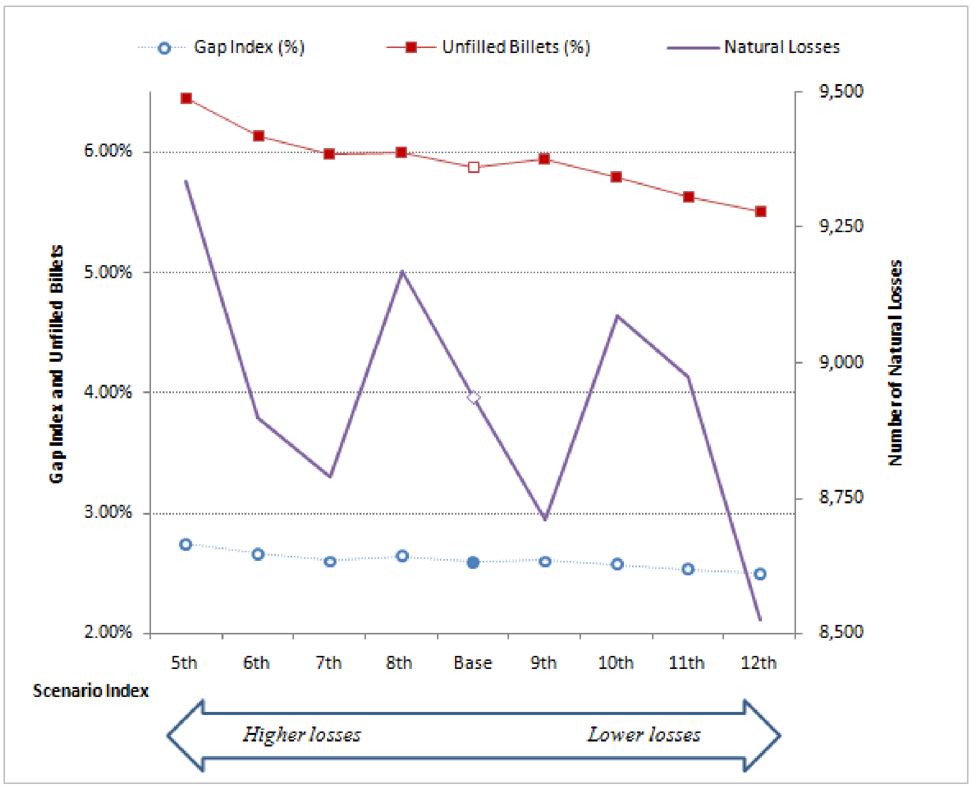


Figure 19. Nine loss scenarios in RCMOP-2: results for gap index, percentage of unfilled billets, and quantity of natural losses.

The maximum and minimum gap index values are 2.74% and 2.50%, and correspond to scenarios High and Low respectively. Likewise, the percentage of billets varies between 6.45% and 5.50%. Natural loss totals fall between 9,336 and 8,525 officers with the lowest losses associated with scenario High. The values shown here vary by up to 15% and are representative of other output data. Given the relatively small variation between the maximum and minimum values (associated with limiting scenarios), in the remainder of this section we only report detailed results on scenarios High and Low.

Item			Scenario High		Scenario Low	
1. Loss Scalar *(annual equivalent)*			i = 1.071		d = 0.905	
2. Gap index			2.74%		2.50%	
3. Percent of billets unfilled			6.45%		5.50%	
4. FY 2009	**Budget Estimate**		$	3,939 million	$	3,939 million
	Personnel Cost		$	3,512 million	$	3,511 million
	Potential Savings		*$*	*427 million*	*$*	*428 million*
5. FY 2010	**Budget Estimate**		$	4,048 million	$	4,048 million
	Personnel Cost		$	3,649 million	$	3,661 million
	Potential Savings		*$*	*399 million*	*$*	*386 million*
6. FY 2011	**Budget Estimate**		$	4,127 million	$	4,127 million
	Personnel Cost		$	3,746 million	$	3,790 million
	Potential Savings		*$*	*381 million*	*$*	*336 million*
7. FY 2012	**Budget Estimate**		$	4,356 million	$	4,356 million
	Personnel Cost		$	3,841 million	$	3,918 million
	Potential Savings		*$*	*515 million*	*$*	*437 million*
8. Officer Flow:		**Starting Inventory**	=	**30,753**	=	**30,753**
		Natural Losses	-	9,336	-	8,525
		Forced Losses	-	1,597	-	1,602
		HYT Losses	-	0	-	0
		OCS Accessions	+	5,910	+	5,910
		USNA/ROTC Accessions	+	6,104	+	6,104
		Final Inventory	=	**31,833**	=	**32,640**

Table 16. RCMOP-2 results: Comparison of highest and lowest loss rate scenarios. (Note: dollar amounts may not add due to rounding.)

3. Gap Index and Unfilled Billets

Table 16 shows that the scenario High has a gap index of 2.74%, while scenario Low has a value of 2.50%. The fraction of unfilled billets mirrors these results with the higher loss scenario leaving 6.45% of jobs vacant, and scenario Low doing slightly better with a 5.50% vacancy rate. In conjunction with Figure 19, we note a trend where loss rates are proportional to both the gap index and percentage of unfilled jobs.

4. Cost and Budget

Scenario High generally uses a smaller fraction of the personnel budget, which increases the potential savings figures (of course, at the expense of more unfilled billets). Annual savings vary between 9.2% and 11.8% for a given FY. Scenario Low remains between 8.2% and 10.9% under annual budget estimates. Fewer personnel implies lower costs and the reduced costs in scenario High are not surprising. As with our previous cost analysis with linear and non-linear penalties, a modest increase in savings during the final FY of each scenario appears, and is likely due to end effects and their impact on forced losses.

5. Personnel Flow

Personnel flows in either scenario are identical with two exceptions. Forced losses are 1,597 officers for scenario High and 1,602 for the low loss case; a nearly indistinguishable difference. Natural losses in these two cases differ by 811 officers, which is 8.6% of the 9,336 personnel losses in scenario High. The OCS accessions selected by the model remain at 125% of the planned figures (i.e., the maximum permitted by RCMOP-2). Final inventories are 31,833 and 32,640 officers for scenarios High and Low respectively, yielding a modest difference of 807 officers.

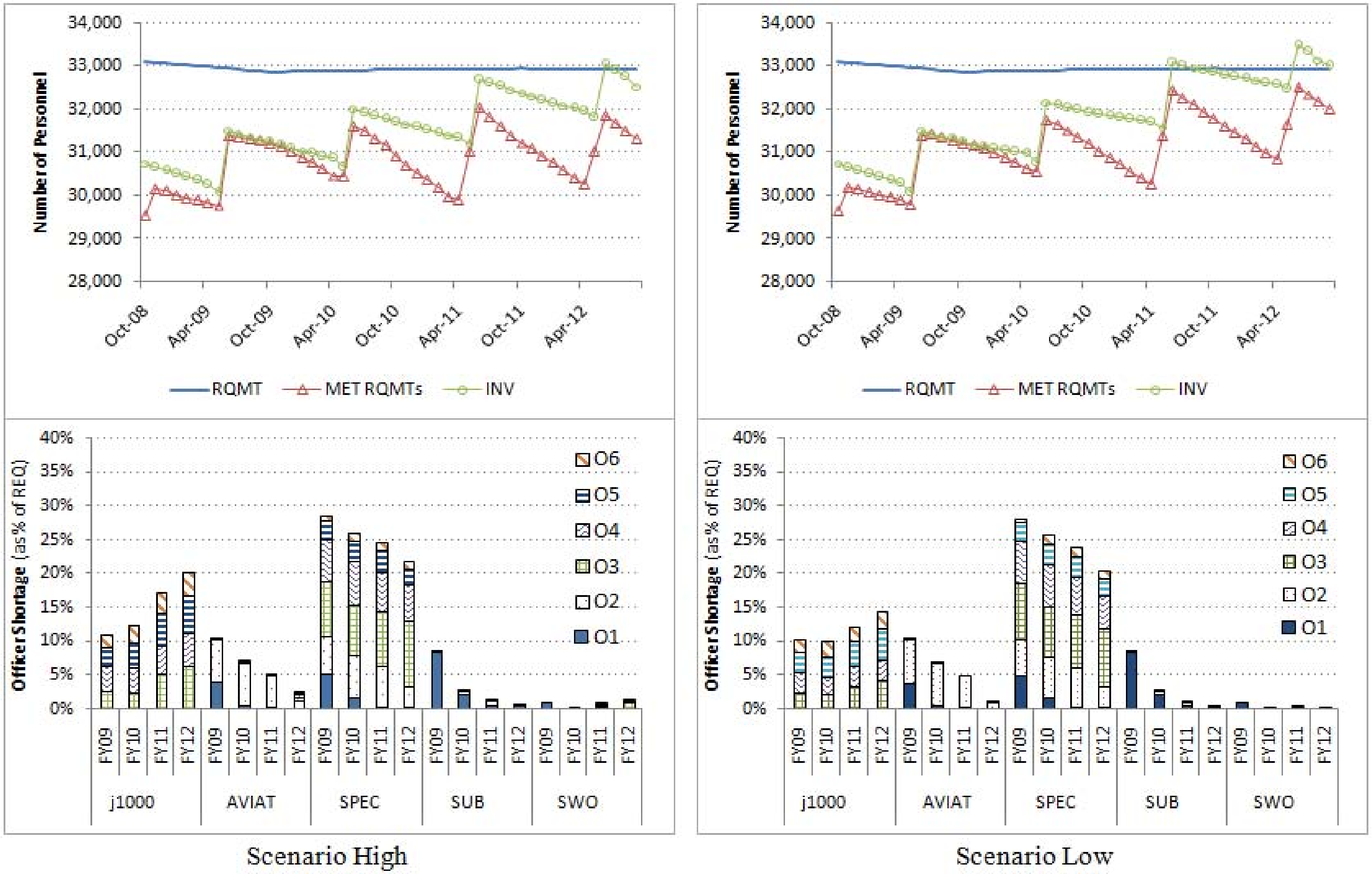


Figure 20. RCMOP-2 results for total personnel requirements, inventory, and met requirements (top figures), and officer shortages (as a percentage of billets required) by rank, designator, and FY (bottom figures). Scenarios High and Low are in the left and right columns, respectively.

6. Inventory, Requirements, and Deficit Analysis

The upper panels of Figure 20 contrast results for our high- and low-loss cases, showing the total billet requirements, officer inventory, and billets filled for each scenario. At a glance, both panels appear indistinguishable, though closer scrutiny reveals subtle differences. Note that in scenario Low, the personnel inventory and met requirements are slightly higher. The initial inventories in both scenarios are equal and over the four-year horizon, the lower loss rates in scenario Low allow it to gradually build a progressively greater inventory (than scenario High). As discussed earlier, the difference between the inventory and met requirements curves widens after April 2010, due to the "O1 saturation" effect and differing loss rates for more senior personnel.

Figure 20's lower panels charts the proportion of officer shortages (relative to their respective billet requirements) aggregated into FYs, for all ranks and selected billet types. The major difference between the two panels is revealed within the `j1000` billets. We find: (1) the Low scenario generally has higher inventory levels in any given FY and (2) the difference in inventories increases over time. These factors result in near parity in officer shortages in FY 2009 between scenarios, but a clear difference becomes evident by FY 2012. In short, for a given time frame, more personnel implies fewer shortages.

Similarities among the lower panels of Figures 14 and 20 exist and include the decrease in shortage over time (excepting `j1000` billets), the decrease in O1 and O2 shortages over time, and the general magnitude of officer shortage in each community (e.g., `SPEC` billets vacancies lie between 20% and 30%).

These lower panels (Figures 14 and 20) also capture the percentage deficit of officers with specific communities, but do not convey the contribution (by billet type) to the total shortfall. Table 17 compares the fraction of requirements and deficits (for scenarios High and Low). Comparing the shortages for both scenarios in any given billet, differences are minimal. `jAVIAT` billets are consistently about a third of both billets required and vacant jobs. In other cases, there is significant mismatch, as seen in the case of the `j1000` and `jSPEC` billets, where these jobs are a significantly larger proportion of the deficit than the billet population. On the other hand, surface warfare officer jobs account for about a sixth of all jobs and only 2% of job shortages.

	Billets	Scenario High Percent of Total Deficit	Scenario Low Percent of Total Deficit
jAVIAT	31%	34%	31%
j1000	10%	22%	24%
jSPEC	4%	17%	15%
jSUB	9%	6%	5%
jSWO	16%	2%	2%
All other billets	30%	19%	23%
Total	*100%*	*100%*	*100%*

Table 17. Percentage of billet requirements and deficits (for high- and low-loss cases) by billet type.

7. Promotions

Table 18 details promotions for our loss scenarios. Again, estimates on promotion rates are omitted, and a large percentage of these fall outside of current guidance. Also, similar to the previous discussion on promotions, the average YCS tends towards the earlier side of the allowable promotion window, reaching the midpoint only once (scenario Low in FY 2011 for O6s). Our prior concerns regarding "below zone" promotions remain after considering these figures.

		Scenario High					Scenario Low				
	to rank	**O2**	**O3**	**O4**	**O5**	**O6**	**O2**	**O3**	**O4**	**O5**	**O6**
FY 2009	**Promoted**	1,624	2,226	1,965	1,024	395	1,624	2,226	1,977	1,002	355
	Avg. YCS	-	-	9.0	15.6	21.1	-	-	9.1	15.6	21.3
FY 2010	**Promoted**	1,632	2,164	1,496	918	466	1,634	2,170	1,465	787	376
	Avg. YCS	-	-	9.4	15.3	21.7	-	-	9.3	15.4	21.7
FY 2011	**Promoted**	2,868	1,520	1,107	838	349	2,878	1,530	1,060	980	385
	Avg. YCS	-	-	9.6	15.2	21.5	-	-	9.6	15.2	22.0
FY 2012	**Promoted**	2,873	1,518	1,521	850	551	2,886	1,537	1,441	754	486
	Avg. YCS	-	-	9.2	15.2	21.2	-	-	9.3	15.5	21.4

Table 18. RCMOP-2 results: Promotion summary for high and low loss scenarios.

Lower loss rates result in higher personnel inventories leading to greater competition for promotion at the control grades. In practice, this tends to result in slightly "slower" promotions (compared to less competitive periods). This can be seen by comparing corresponding average YCS between scenarios, where values for scenario Low are higher than or equal to those in scenario High in all but one case.

8. Transfers, Forced Losses, and End Effects

Transfers (to include concurrent promotions) are outlined in Table 19. The total quantity of transfers between scenarios is nearly identical, and row totals (indicating numbers of personnel leaving a certain designator) are roughly equivalent. On the other hand, column totals (i.e., which designators are receiving officers) show some differences. The intelligence community receives nearly 1,000 more officers in scenario High; the bulk of this difference comes from the surface warfare community. End effects are a likely cause for this behavior, because 538 more officers are transferred during the final month of scenario High than scenario Low. Of these 538 officers, 389 are `SWO`s transferred into the `INTEL` community. Actual transfers in the final month are 686 and 148 for scenarios High and Low, respectively.

	From / To	INTEL	RL.OTH	CEC	SUPPLY	Total
Scenario High	**AVIAT**	2,267	825	29	93	*3,213*
	SPEC	-	-	-	9	*9*
	SUB	124	354	60	99	*638*
	SWO	1,526	1,723	270	215	*3,733*
	Total	*3,917*	*2,902*	*359*	*416*	***7,594***
Scenario Low	**AVIAT**	1,990	982	33	277	*3,281*
	SPEC	-	-	-	10	*10*
	SUB	76	404	97	138	*715*
	SWO	852	1,719	546	435	*3,553*
	Total	*2,918*	*3,106*	*676*	*859*	***7,559***

Table 19. RCMOP-2 results: Transfers for high- and low-loss scenarios.

Significant evidence of end effects remains present in values of forced losses as seen in Table 20, consistent with prior results.

Forced Losses			
	Total over 48 months	*Total over final 6 months*	
	Quantity	**Quantity**	**Percent**
Scenario High	1,597	1,109	69%
Scenario Low	1,602	1,093	68%

Table 20. Evidence of end effects in RCMOP-2: Comparison of forced losses over 48 months and final six months for loss scenarios High and Low.

V. CONCLUSIONS AND SUGGESTED FUTURE RESEARCH

This research has demonstrated improvements to RCMOP, a manpower planning optimization model for the U.S. Navy, which minimizes the mismatch between personnel inventory and billets required while enforcing budget and other manpower constraints. The new model, called RCMOP-2, adds more fidelity to the data, and has been analyzed under newly added nonlinear penalties and multiple scenarios of loss rates. This chapter reports the most significant findings of that analysis and recommends prospective areas for improvement.

A. SIGNIFICANT FINDINGS

1. Higher Fidelity Improves Model Results

Five personnel designators and six billet types in RCMOP have been expanded into nine and ten categories, respectively, in RCMOP-2. RCMOP's most general personnel classification, `OTHER`, initially contains 8,846 officers, which accounts for 29% of the inventory. By comparison, RCMOP-2's most generalized officer category contains 4,052 (13% of initial inventory). Additional personnel and billet classifications in RCMOP-2 provide corroborating support into additional communities and improve the realism of the model by reducing the number of unauthorized assignments.

Secondly, the time horizon of the model has been doubled from two to four years. This has a significant impact, particularly at the ranks of O2 and below. O1s and O2s account for 62% and 56% of annual officer shortages in the first and last years, respectively, of the two-year RCMOP model; a 6% difference. Over RCMOP-2's four-year timeframe the difference is 48%, with a first year contribution of 58% being reduced to 9% by the fourth year.

More resolution in the data may, at some stage, reach a point of diminishing returns, whether due to file sizes, pre- and post-processing of information, or computational times for model runs. The improvement shown in RCMOP-2 suggests that we have not yet reached this threshold.

2. Non-Linear Penalty Enhancements

The objective function is improved through the use of non-linear penalties. These penalties allow planners to establish the relative importance of a billet's shortfall based not only on the type of job, but also on the number of unfulfilled billets for that job. For example, the 1000-coded billets have the lowest weight and therefore are the first jobs that RCMOP-2 decides to leave unfilled. However, given that the more unfilled jobs of a given type the higher the penalty rate becomes, RCMOP-2 eventually chooses other jobs, reducing the fraction of unmet 1000-coded requirements with respect to RCMOP. Dispersing unfilled requirements more evenly across multiple categories is consistent with current practice.

3. Loss Rate Explorations

Our premise for investigating loss rates is that natural loss rates should have significant impact on RCMOP-2's output. We vary natural loss rates, predicated on historical values, between 0.74 and 1.22 of the average FY 2006-2008 loss rates (our baseline values) over the final three years of the model's horizon. The difference in final inventory levels between our highest and lowest loss scenarios is 807 officers, and the differential in the numbers of natural losses, 811 officers, accounts for the inventory differential.

Comparison of the highest and lowest loss scenarios reveals consistencies between the fractions of unfilled billets in each scenario. Contrasting the billet vacancy percentage with the billet requirements percentage offers insight on which communities are having problems satisfying billet needs. Aviators consistently represent about a third of all billets required and unfilled billets. The 1000-coded billets and Special Warfare/Operations billets show adverse mismatch between these figures, where their percentage of the billet vacancy is two to four times higher than their percentage of billet requirements. The surface warfare officer community demonstrates favorable mismatch in the model, accounting for roughly 16% of all jobs, yet only 2% of unfilled billets. Our results and analysis of loss rates suggests that RCMOP-2 may be less sensitive to this parameter than initially suspected.

4. Increase OCS accessions

In every scenario, RCMOP-2 consistently recommends increasing OCS accessions to 125% of the planned accessions in any time period, which is the maximum permitted accession rate. This is a clear signal that accessions should be increased in order to better meet future requirements. Given the four years officers normally spend in ranks of O1 and O2 (two years apiece), the model fully leverages OCS accessions to significantly reduce penalties for O1 and O2 ranks in the four-year horizon.

5. Potential Cost Savings

Budget estimates used in RCMOP-2 never become a binding constraint. The model consistently reports annual personnel costs approximately 8-12% below budget outlays. Due to end effects observed in the model, the final FY normally produces the highest savings, and the above figures may be smaller in reality. As the Navy's budget becomes more pressurized due to mounting internal and external forces, this information on potential savings may be useful for planners.

B. RECOMMENDATION FOR FUTURE RESEARCH

1. Time Horizon

RCMOP-2 uses a four-year horizon. Despite this is an improvement with respect to RCMOP, it still presents two problems: examination of the control grades (O4 through O6) and end effects.

The control grade inventory problem relates to the military manpower scheme; The Navy does not "hire" O4 officers, but rather "grows" them by hiring O1s about a decade earlier. Accessions in the first month of the model progress only to become freshly minted O3s in the final month. The initial inventory used by RCMOP-2 reflects some shortfalls in the control grades. Given that we use only a four-year horizon, RCMOP-2 is unable to correct problems (e.g., “hire” control grade officers), and can only work to limit the penalty this group incurs.

End effects manifest themselves through abnormal behaviors by several decision variables in RCMOP-2. Analysis suggests that forced losses, personnel costs, and transfers may experience end effects to varying degrees, though other variables may be impacted as well.

Shifting from monthly to quarterly time steps in the current model would cover a twelve-year period, and would begin to address long-term solutions at the O4 level. We recommend exploring longer time horizons of up to 25–30 years.

2. Weights

Weights used in the model are subjective, and bear a clear caveat: weights are not tied to any formal or informal guidance from Navy leaders or written policy. In addition to correcting the subjectivity, the dimensionality of the weights could be improved as well. Currently weights are only differentiated by designator. That is, the superior knowledge, skills, abilities, and experience of the O6 (compared to an O1) are not accounted for in the establishment of the baseline penalties.

Navy Guidance on the relative importance of job *and* ranks is needed to improve the model for potential use by Navy manpower planners. Job importance must reflect and align with the long-term plans of Navy leaders. Relative rank importance should echo these designs as well, though personnel compensation (e.g., military pay tables) provides some objective and empirical insight to the relative rank importance as a baseline estimate.

3. Future Resolution Improvements, and 1000- and 1050-Coded Billets

Additional resolution may continue to improve RCMOP-2 performance. The NOC should be the source used for determining future resolution improvements.

One specific improvement relates to the `j1000` billets in the model. RCMOP-2 combines the 1000- and 1050-coded billets, each of which is about five percent of the total billet requirements. In reality, intelligence and other restricted line officers are eligible for only half of these jobs (1000-coded billets), while unrestricted line officers above the rank of O3 are eligible for both 1000- and 1050-billets. The model allows the intelligence and other restricted line communities to fill both jobs. Typically, RCMOP-2 builds excess personnel in these two officer groups, and leverages these excess to fill the majority of `j1000` billets (to include 1050-coded billets for which they are actually ineligible). Future resolution improvements should include segregation of the 1000- and 1050-coded billets.

4. Prior Service Impacts

To remove our assumption that YCS and YOS are equivalent, additional data is needed, such as distributions governing the quantity of officers with prior service and the length of prior service, for each rank. A weighted average using these distributions could be used to calculate associated costs for these officers. The change of these distributions over time poses a serious problem, though assuming a constant distribution would still be an improvement from the current model.

5. Improving the Gap Index

Though the objective function of RCMOP-2 is sound, the interpretation of its values can be vague and potentially misleading. Our derived datum $\overline{w}$ calculates the maximum possible penalty in a given scenario where every job is vacant. This value is very large relative to the actual penalty finally observed, given the officer population.

That is, using $\bar{w}$ to normalize the objective function artificially depresses the value of the objective function, yielding minimal absolute differences in the gap index (e.g., only 0.0024 between the nine loss scenarios).

Further confusion arises when comparing scenarios with different penalty functions. For instance, in scenarios 1 (with nonlinear exponent $x = 1$) and 4 (with $x = 2.5$), clearly $\bar{w}_1 < \bar{w}_4$. Even if we assume the total penalties accrued were equal for both scenarios (e.g., numerators of the objective functions are equal) the gap index of scenario 4 would be smaller due to the larger value of $\bar{w}_4$, though this scenario may not be superior to scenario 1. Devising an improved metric to allow fair comparisons to be made between scenarios *m* and *n* when $\bar{w}_m \neq \bar{w}_n$ remains a challenge.

6. Further Loss Rate Analysis

Current analysis is performed under the context of "perfect information" and does not easily allow for so called "what if" analysis. Among these, planners may find useful exploring impacts on decisions premised, for example, on a low loss scenario, when a high loss scenario occurs.

The existing model could be extended to provide strategic guidance *today* based on "imperfect information." For example, this notional extension would recommend the best manpower plan *now*, assuming *n* outcomes in one year, n^2 possible outcomes after two years, and n^3 outcomes three years in the future. Such analysis would be very helpful for Navy leaders and manpower planners in order to mitigate future risks in balancing personnel inventories and billet requirements under uncertain losses. An extension of this nature would require the use of stochastic optimization.

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